Family Engineering for Elementary-Aged Children and Their Parents

Neil J. Hutzler[1], Joan S. Chadde[1], David Heil[2], and Mia Jackson[2]
[1]Michigan Technological University, Houghton, MI [2]Foundation for Family Science and Engineering, Portland, OR

Abstract

The goal of the Family Engineering program is to engage, inspire, and encourage elementary students to learn about and consider careers in engineering and science through hands-on activities with their parents at Family Engineering events. This program is designed to address the United States' need for an increased number, and greater diversity, of students skilled in math, science, technology, and engineering. The Family Engineering program for 6-12 year-olds and their parents is modeled after the popular *Family Science* and *Family Math* programs. Family Engineering increases public understanding and appreciation of the role engineering plays in everyday life and encourages parents and children to consider engineering as a career. Student chapters of professional engineering organizations on college campuses, elementary classroom teachers, engineering professionals, and informal educators at museums are likely to want to host Family Engineering events.

A set of family engineering activities representing typical engineering disciplines and concepts has been developed and field-tested to determine its suitability to a wide range of settings and audiences. The family engineering activities were assessed at 8 sites (in California, Connecticut, Georgia, Michigan, Mississippi, Puerto Rico, Utah, and Wisconsin) during spring 2010 with positive results. Activities fall into three categories – icebreakers, short or opener activities, and longer engineering challenges. The opener activities are set up in advance and are self-paced so families can work on them as they arrive at an event. Icebreakers draw attention from the short activities, bring the participants together, and set the tone for the rest of the event. The engineering challenges engage families in the engineering design process. Participants are challenged with an engineering problem such as designing a thing or a process. They ask about the challenge, imagine various solutions, plan a specific solution, create the thing or process, and then improve on their designs. Field test activities and events were evaluated by event participants, facilitators, and experts in education and engineering. The results have shown that most of the activities that were developed are fun and engaging and that children and their parents experienced significant increases in their interest in and awareness of engineering in their everyday lives as a result of the program. Parents also reported an increase in their willingness to consider engineering as a possible career option for their children.

Introduction

The demand for scientists and engineers is growing steadily, but the US is unable to meet that demand. The resulting shortage of technically skilled employees threatens national economic and technological competitiveness. Often pre-college students have not been introduced to science, technology, engineering, and math (STEM) in a way to attract them to the fields as a career. This has been particularly challenging for the engineering field, since specific instruction in engineering is quite limited in K-12 settings, with most engineering offerings not appearing until the high school years. In an effort to increase awareness, programs such as "Engineering is Elementary" and "Project Lead the Way" have developed curricula that can be used in school settings, and programs such as FIRST have been developed to pique interest in engineering and science though competition. But, none of these programs actively engage parents and children in exploring engineering together.

Parents play an important role in developing their children's career interests by providing support, guidance, career and educational suggestions, and life experiences that support career development[1]. Therefore, a child's elementary years are an ideal time for engaging parents in informal science and engineering education programs. Because parental influence plays a key role in children's educational achievements, parent/family involvement is an essential part of the solution to the looming STEM crisis. Studies have found that student achievement increased directly with parental engagement[2]. When parents participate in their children's education, students' achievement and attitudes improve[3]. Other benefits include higher aspirations for school and career development[4]. Over the past two decades two programs have demonstrated the power of parent/child learning in science and mathematics. These programs with their respective publications, *Family Science*[5], and *Family Math*[6], have offered teacher/parent trainings and hosted events for families in communities across America and around the globe, successfully engaging families with elementary age youth in hands-on science activities and problem solving. By introducing science and math concepts early, these programs are helping to increase parents' and children's interest and confidence in doing science and math, as well as providing parents with resources for encouraging their children to study science and math in school and consider possible careers in these fields. These two programs have been particularly successful at reaching out to families traditionally underserved in science and math, including families from inner urban, rural, and minority communities. Both programs offer publications and program delivery in both English and Spanish to assist in reaching diverse audiences.

In its report *Changing the Conversation*[7], the National Academy of Engineering concluded the public image of engineering needed to reflect the optimism and aspirations of students and needed to be inclusive. Some of the misconceptions included 1) engineering work is a sedentary desk job, 2) engineering is strongly linked to math and science, but not to other vital aspects, such as creativity, teamwork, and communication, and 3) engineers are not seen as directly helping people. NAE observed that many kids want a well-paying job that makes a difference – something that can easily be linked to engineering.

Family Engineering is being developed to provide a vehicle to promote early interest in, and a better understanding of engineering through the use of fun, hands-on activities designed to present basic engineering concepts and skills to families with elementary age children. By actively engaging families in these activities, the program is helping to lay a foundation for future learning in STEM related fields and for increased parental confidence and comfort with encouraging their children to study STEM topics in school and consider a possible career in engineering. Initial program research and development is being supported through a grant from the National Science Foundation. The purpose of this paper is to briefly summarize some of the features of the Program.

Goals of the Family Engineering Program

The goals of Family Engineering are 1) to engage families in engineering with fun, hands-on activities, 2) to increase public understanding and appreciation of the role engineering plays in everyday life, 3) to introduce children at an early age to the many career opportunities in engineering, 4) to increase parents' interest in and ability to encourage their children to pursue an engineering career, and 5) to provide age-appropriate resources to support volunteers in conducting informal engineering education programs with elementary-aged children and their parents. These goals are accomplish by conducting events in informal community settings.

In the development phase of the Family Engineering Program, consideration was given to what families need to know about engineering. The project team developed the following list:

- Engineering is the use of imagination, along with science and math knowledge, skills, and experience, to address challenges and design solutions.
- Science, math, technology, and communication are important tools for engineers
- Engineers are creative problem-solvers
- Engineers improve people's lives and make the world better
- Engineers help shape the future
- Engineering problems usually have multiple solutions
- Engineers are from all races, ethnicities, and genders
- There are many different fields of engineering
- There are many great career opportunities in engineering

Family Engineering Program Components

As mentioned above, the Family Engineering program is being modeled after two previously developed and successful programs – Family Science and Family Math. Key program components include the following:

- Publication of a book of hands-on activities titled *Family Engineering: An Activity and Event Planning Guide,* with both English and Spanish language editions. Included in the book are suggestions for how to foster engineering learning in the home and other informal, non-school settings, as well as how to reinforce the importance of science and math course work in school. In addition, the publication provides information and resources for hosting Family Engineering events in school and community settings.

- A variety of tested event formats for implementation by volunteers trained to facilitate and host Family Engineering events in their community. These formats are described in more detail later in this article.
- Professional training opportunities for educators, engineers, and STEM undergraduate students interested in volunteering to help host and/or facilitate Family Engineering events and activities in their community.
- An interactive website with additional resources and materials to support families, trained volunteers, and others interested in implementing Family Engineering in their community.

Development of Family Engineering Activities

A number of dimensions were considered in designing successful activities for Family Engineering. Based on the development team's prior experiences with Family Science and research on teaching and learning in informal settings, the following were identified as important characteristics of a Family Engineering activity:

- *Encourages Family Interaction*: the approach, activity design, and materials invite and encourage parents and caregivers to work and learn together with their elementary-aged children.

- *Fun and Engaging*: activities are informal, enjoyable, and maintain the interest of participants; spark a desire to continue learning about engineering; create positive associations with engineering; create feelings of confidence and ability with relation to engineering

- *Original Material:* activities should provide a new and novel way of exploring engineering concepts; avoid activities that have already been published or are common practice in the informal science, engineering, or enrichment education field.

- *Inherent Engineering Connection*: a connection to engineering content and/or engineering careers is obvious and built in to the context and facilitation of the activity.

- *Approachable and Accessible*: activities require no specialized knowledge of engineering to participate or facilitate; activities are designed so that participants and facilitators feel confident and capable in completing them; activities are appropriate for and inviting to diverse audiences (socially, ethnically, economically, geographically, academically, and culturally).

- *Relevant to Elementary-Aged Children and Their Parents*: activities deal with challenges and subject matter that are relevant, interesting and meaningful to children in grades 1-5 and their parents.

- *Promotes Problem-Solving*: activities encourage finding multiple solutions through inquiry, testing, and teamwork.

- *Simple, Inexpensive Materials*: materials should be easy to acquire, simple to use, and able to be gathered in large quantities for events without a large expense.

- *Safe*: materials and methods for an activity must provide for safe engagement at home or within the open structure of an informal public event. In particular, short activities need to be safe and functional without any facilitation or supervision.

- *Written for Facilitator*: the primary audience for Family Engineering activities is the individual who will be planning and implementing Family Engineering events for elementary-aged children and their families. Parents may also be facilitators at schools, home, or community settings.

- *Suitable for a Variety of Settings*: schools, community centers, churches, homes, museums, etc.

In addition to having the above features, there are a number of engineering concepts and skills that are introduced and reinforced. This list includes:

- *Engineering design process*: A series of steps that engineers use to guide their problem-solving. Family Engineering has adopted a simple 5-step version of the design process used by the Engineering is Elementary (EiE)[8] curriculum - Ask, Imagine, Plan, Create, Improve.
- *Teamwork*: the ability to function on multidisciplinary teams.
- *Open-ended problem-solving*: the ability to identify, formulate, and solve problems.
- *Communication*: the ability to communicate effectively with others.
- *Societal and environmental impact*: the ability to understand the impact of engineering solutions in a global, economic, environmental, and societal context.
- *Design under constraints*: the ability to design a component, product, or system to meet a desired outcome or solution while accommodating a range of constraints. Constraints may be economic, environmental, social, political, ethical, health and safety, manufacturability, materials, or sustainability-related.
- *Controlled experimentation and testing*: the ability to design and conduct experiments, as well as analyze and interpret data. Understanding of what constitutes a “fair” test.
- *Role of failure*: the recognition that failure plays an important role in the design process and is not necessarily a negative outcome; learning to use failure to find a better solution.
- *Reverse engineering*: the deconstructing, or taking apart, of a product or process to figure out how it works.
- *Systems*: the ability to design systems, where many processes must work together.

- *Optimization/trade-offs*: the ability to make trade-offs, or optimize a process, in order to enhance its benefit and minimize negative impacts.
- *Spatial visualization*: the ability to envision 3-D models from 2-D drawings and to "see" how things fit together.
- *Modeling*: the recognition that designs can often be optimized by building models and/or by constructing and testing prototypes prior to building a final product.
- *Properties of materials*: the ability to select the proper material for a given product; recognizing that the properties of a material will determine how that material contributes to a solution.

Forty family engineering activities have been developed. These activities fall into three categories: 1) short, self-directed activities 2) icebreakers, 3) longer, facilitated engineering challenges. Table 1 gives examples of the short activities and the engineering challenges. The short activities have been designed to set up before an event so that families can begin working on them as they arrive at an event location. A short activity will typically take one to five minutes to complete. It encourages quick parent/child engagement, and no supervision or facilitation is required. An easy-to-read sign is placed next to the activity materials, and families work through a simple, hands-on activity that introduces only one or two engineering concepts. Materials are easy to reset or replenish for the next family. The signs also include a short engineering connection explaining the basic engineering concept represented.

Table 1. Examples of Family Engineering Activities.

Name of Activity	**Engineering Hook**	**Engineering Field(s)**	**Type of Activity**
Opener Activities			
Diving Board Dominoes	How far out can you build a cantilever?	Civil Engineering, Mechanical Engineering	Hands-on building
Inspired By Nature	What human inventions have been inspired by natural objects?	General Engineering	Card matching
Solid Ground	What granular material makes the best base?	Geological Engineering	Hands-on testing
Thrill Seekers	Build a roller coaster with turns and loops.	Mechanical Engineering	Hands-on building and testing
Engineering Challenges			
Assembly Line	Design an assembly process to minimize time of assembly	Industrial Engineering, Manufacturing Engineering	Hands-on design

Blast Off	Design and test an air-launched rocket made from specified materials	Aerospace Engineering	Hands-on design and testing
Give Me a Hand	Design a mechanical device to pick up a selection of different objects	Biomedical Engineering, Mechanical Engineering	Hands-on design and testing

An icebreaker activity is used to quickly focus family participants' attention and allow the facilitator to welcome the group and provide an overview of the event. The icebreakers typically introduce families to engineering as a profession and highlight common misconceptions about the field. They can also be used at the end of an event to help bring closure.

Longer, facilitated activities are designed to engage families in more in-depth problem solving and hands-on engineering challenges. They typically take 20-40 minutes to complete and emphasize parent/child interaction and active engagement. Instructions for facilitators include descriptions of recommended discussion questions, materials distribution strategies, and group facilitation techniques. They may also include extensions for when additional time is available or take-home ideas to encourage continued family learning and exploration. They include necessary hand-outs or activity sheets, and include a cultural connection and/or fascinating facts about the concept or engineering field featured in the activity.

Family Engineering Events

The *Family Engineering* publication serves as a resource for individuals or organizations wanting to provide informal engineering education opportunities to elementary-aged children and their families through fun and engaging community events. In addition to a collection of hands-on engineering activities, the book provides all the tools necessary to plan, organize and implement a successful Family Engineering event. A number of specific target audiences have been identified as potential event facilitators and users of this resource – professional engineers and engineering societies, student chapters of engineering societies, informal educators, formal K-5 teachers, and parents.

The Family Engineering Program has developed a variety of successful, proven event models for implementing a Family Engineering event. A typical Family Engineering event will last from 1½ - 2 hours as shown in Table 2 and begins with a variety of short activities – engaging experiences set up as table-top stations – available for families to explore at their own pace as all participants are arriving. After enjoying the short activities on their own, families are gathered together as a large group to be welcomed and oriented to the next part of the event. At this time, an icebreaker activity can be used to loosen up the group and get families thinking about engineering and how it impacts their everyday lives. Following these shorter "openers" and "icebreakers" event facilitators introduce families to longer activities that allow them to more deeply explore an engineering concept or discipline or experience the engineering design process first hand.

The longer, facilitated activities may last from 20-40 minutes each and allow families to work together to solve an engineering challenge or explore an engineering topic in more

Table 2. Typical Family Engineering Event Schedule.

Time	Event Activity
2 hours before event start time	Arrive at venue and set up event
30 minutes before start	Brief event volunteers
Event start time	Families arrive and begin working on opener activities at their own pace
30 minutes after start time	Families brought together to be welcomed to the event and learn about engineering
40 minutes after start time	Families work on engineering challenge activities
100 minutes after start time	Wrap up the event
110 minutes after start time	Clean up (takes about 30 minutes)

depth. This portion of the Family Engineering event can be implemented in a variety of formats. Two different formats that have been developed and field-tested include:

- A facilitator leads the entire group, working in family teams, through 2-3 facilitated activities. Other staff/volunteers assist with distributing materials and helping families engage in activities.

- Participants split into smaller groups, with participants remaining in their family units, to participate in 2-3 facilitated activities conducted in separate rooms with two or more activities occurring simultaneously. Families rotate through 2-3 different activities during this event format.

Following the longer activities, event participants can be brought back together as a group to share some of their learning outcomes and new perspectives on engineering, and be made aware of the *Family Engineering* publication, website and other Family Engineering related resources available to support their further exploration of engineering. If appropriate, take-home materials can be provided to encourage families to continue exploring and learning together.

A Family Engineering event can also be a wonderful opportunity for participants to meet and interact with professional engineers or engineering students. If any of the facilitators and/or volunteers for an event is a professional engineer or engineering student, some time may be dedicated to introducing them to the group and having them answer career related questions from the audience or facilitate a Family Engineering activity that focuses on engineering careers.

Evaluation and Expert Review

The activities and event formats were recently tested (spring 2010) at select locations in California, Utah, Michigan, Wisconsin, Mississippi, Georgia, Connecticut, and Puerto Rico.
Each site hosted a minimum of five events presented to a broad range of audiences representing different community locations, socio-economic levels, ethnic backgrounds, and facilitation models. Field Test Coordinators have also come from diverse backgrounds in order for the project team to test viability of various volunteer demographics and backgrounds. During the Field Test period from February through May of 2010, Family Engineering events and activities were facilitated by engineering university faculty, undergraduate students enrolled in STEM programs, teachers, professional engineers, informal educators, and some parent volunteers. Events have been held in elementary schools, science centers, community centers, and corporate settings in order to test a range of locations and facilitation formats and delivery.

At each of the field test events, evaluative feedback was gathered from participating families, volunteer facilitators, and site coordinators. For example, Table 3 summarizes average responses of all of the families during field testing to several questions assessing the impact of the events. They show that families significantly increased their interest in and awareness of engineering, and that they would consider encouraging their children to consider engineering as a career. Other results from this formative evaluation were used to guide final development of the activities published in the *Family Engineering* guidebook.

Table 3. Impact of Family Engineering Event during Field Testing.

	Before attending Family Engineering we were ….	**After attending Family Engineering we were …**
Interested in engineering.	3.52	4.53*
Considering engineering as a possible career option for our child/children.	3.45	4.33*
Aware of the connections between engineering and everyday experiences.	3.45	4.59*
Aware of what engineers do.	3.53	4.67*

**Change in mean is significant based on a paired sample t-test, p-value <0.05.*
Average Rating based on a scale from 1 (strongly disagree) to 5 (strongly agree).

During the field test phase, a cadre of professional engineers, engineering educators, and experienced formal and informal educators were identified to conduct expert reviews of the draft Family Engineering materials. This review, facilitated by the formative evaluation team, provided expert opinion on the engineering content and educational pedagogy reflected in the activities being developed. The reviewers' comments helped inform the refinement of the Family Engineering program.

Summary

A program has been developed that includes publication of an activities and event planning guidebook, development of a web site, and provision of training for facilitators. The activities and event formats were extensively tested under a range of settings and with a range of audiences. It was determined that Family Engineering events significantly increased a family's interest in engineering and engineering careers.

Bibliography

1. Altman, J.H. (1997). Career development in the context of family experiences, *Diversity and Women's Career Development: from Adolescence to Adulthood*, edited by Helen S. Farmer, pp. 229-242. Thousand Oaks, CA.

2. Jordan, et al., (2002). Emerging issues in school, family, & community connections. Austin: National Center for Family & Community Connections with Schools, Southwest Educational Development Laboratory.

3. Henderson, A. and N. Berla, 1994. A New Generation of Evidence: The Family Is Critical to Student Achievement. Washington: Center for Law and Education. ED375968.

4. Caplan, Hall, Lubin, and Fleming (1997). Parent Involvement: Literature Review and Database of Promising Practices. North Central Regional Educational Laboratory.

5. Heil, D., et al. (1999). *Family Science*. Portland, OR: Portland State University.

6. Coates, G.D. and V. Thompson (2003). *Family Math II*, Berkeley, CA: University of California at Berkeley8.

7. National Academy of Engineering (2008). *Changing the Conversation: Messages for Improving Public Understanding of Engineering*, Washington DC.

8. Cunningham, C.M. (2009). Engineering is Elementary. *The Bridge*, 30(3), 11-17.

Bibliographical Information

NEIL HUTZLER is a professor of civil and environmental engineering and the director of the Center for Science and Environmental Outreach at Michigan Technological University. He has over 30 years of experience in engineering education in both K-12 and higher education.

JOAN CHADDE is the education outreach coordinator for the Center for Science and Environmental Outreach at Michigan Technological University. She has more than 25 years experience in science and environmental

education, water resource management, and professional development including the design and implementation of numerous K-12 science and engineering programs.

DAVID HEIL, president of David Heil & Associates, Inc., is well known as an innovative educator, author, and host of the Emmy Award winning *Newton's Apple* on PBS. Active in promoting public understanding of science for over 30 years, he is a frequent presenter on STEM education.

MIA JACKSON, an associate with David Heil & Associates, Inc., specializes in program and exhibit development, project management, and evaluation with emphasis on early learning, parent/child engagement, and public outreach.

Development of Infrastructure Materials Course for Undergraduate Students in Civil Engineering

Eshan V. Dave
Assistant Professor, Department of Civil Engineering, University of Minnesota Duluth.

Abstract

This paper describes the development of Infrastructure Materials course for undergraduate students in civil engineering. The course comprises of balanced lecture and laboratory components and serves as a core course for future civil engineers. The course spans a variety of materials ranging from steel to Portland cement concrete. The lecture component of the course focuses on topics associated with origin and manufacture of materials, physical and mechanical behavior and material design. The laboratory component focuses on evaluation of material properties in accordance with ASTM specifications, making comparisons between different materials and determining whether material meet the necessary requirements for various civil engineering applications.
The course is designed to meet and exceed several ABET required outcomes. The key outcomes assessed through this course include: ability to effectively communicate, ability to conduct laboratory experiments and to critically analyze and interpret data, and ability to function in multidisciplinary teams. Along with details on the development of course syllabus and its implementation, this paper also describes the efforts that were undertaken to evaluate the aforementioned objectives and presents results from two consecutive semesters.

Introduction

The infrastructure materials course is a core course that is commonly offered at sophomore and junior level to civil engineering undergraduate students. At the University of Minnesota Duluth (UMD), this course was developed to be offered at junior level. The development of the course syllabus is discussed in this paper along with results for various ABET outcomes that are being evaluated through this course. The course was offered for first time at UMD during fall 2010 semester. This course is offered twice every year (fall and spring) to ensure that class size is balanced as approximately 35 students. The enrollment during fall semester was 34 students and in subsequent spring semester it was 12 students.

The main objective of this class is to teach students about various types of infrastructure materials. This class is designed to help students gain knowledge on following topics related to infrastructure materials:

- Selection criteria and considerations;
- Behavior of materials for different types of loading and boundary conditions;

- Fundamental and engineering properties of interest and their evaluation through laboratory testing;
- Design of construction materials (Portland cement concrete and asphalt concrete);
- Specifications for acceptance of materials; and
    - Insight on sustainability of infrastructure materials.

In order to achieve the above listed learning objectives the course follows an integrated lecture and laboratory schedule. A total of twelve two-hour long laboratory sessions are conducted through the course of semester. For each lab session, students are asked to review ASTM specifications, follow the procedures from the specifications to conduct experiments, and collect and analyze data.

Course Topics and Organization

The course is broken down into series of learning blocks with established objectives for each block. Students are provided with detailed schedule for each learning block and corresponding objectives at the beginning of the semester. These are also revisited at the beginning of each learning block. While a detailed list of learning objectives for each block is not provided here for brevity, the list of topics, approximate number of lectures and a brief description is as follows:

(1) Behavior of Materials (3 Lectures): This block discusses various types of physical and mechanical behaviors of solids and fluids. Topics such as elasticity and inelasticity, linearity and non-linearity of materials, constitutive equations etc. are discussed during this block. One laboratory session is conducted to familiarize students with various measurement devices as well as to conduct laboratory safety training.
(2) Steel and Aluminum (4 Lectures): Manufacture of steel and aluminum are discussed along with mechanical and physical properties of interest, laboratory procedures to obtain these properties and, commonly used standards and specifications for metals in construction industry. Two laboratory sessions are conducted in this block; experiments include tensile testing of various metals, hardness measurements and toughness testing.
(3) Aggregates (3 Lectures): This block briefly discusses geological aspects associated with mineral aggregates followed by extraction and manufacture. Physical properties and size distributions (gradations) are discussed along with requirements for various construction materials and projects. This block also consists of two laboratory sessions that involve measurements of specific gravities, relative densities, void content, absorptivity, and shape and texture measurements for coarse and fine aggregates.
(4) Portland Cement, Portland Cement Concrete and Masonry (9 Lectures): Cement manufacture and hydration processes are discussed during the initial portion of this block. Effects of admixtures on cement hydration as well as strength gain is discussed next along with laboratory tests for measurement of cement hydration rates as well as setting

times. One of the key objectives of this block is to teach the volumetric mix design method for Portland cement concrete (PCC). Mechanical and physical properties of fresh and hardened PCC are discussed along with various requirements associated with different types of construction projects. Brief introduction is given to masonry and clay bricks as well as tests and specifications associated with them. A total of five laboratory sessions are conducted during this block. These include setting time tests on cement paste, cement mortar testing, PCC mix design, testing of fresh PCC for workability, yield and air content and, mechanical tests on hardened and cured concrete samples.

(5) Asphalt Binder, Asphalt Concrete and Introduction to Flexible Pavements (9 Lectures): This block discusses the extraction and manufacture of asphalt binder, specification methods for asphalt binder, various laboratory characterization tests for binders and issues associated with pavement performance in context of aforementioned tests and properties. In second set of lectures the volumetric design of asphalt concrete is taught along with various mechanical tests and construction issues associated with the asphalt concrete and flexible pavements. A brief introduction is given on design of flexible pavements. One laboratory session is conducted for this block that deals with testing of asphalt binder and determining volumetric properties of asphalt concrete.

(6) Wood (3 Lectures): This block introduces various species of timber along with specifications for structural timber sections. Physical and mechanical properties of interest are discussed along with wood preservation and degradation.

(7) Composites and Sustainability of Infrastructure Materials (3 Lectures): The concept of composite design and use of analytical and approximate models to determine their properties are introduced in this block. Design of engineered systems is discussed along with various measures for evaluation of renewability and sustainability of construction materials.

During the laboratory sessions the students are asked to work in groups of 3 to 4 students. During the course of semester three professional reports are prepared by students. These reports are expected to describe student's lab activities, data collection, data analysis, and findings and recommendations. For each set of labs corresponding to the report a new set of lab groups are assigned. The lab groups are made using a random process. Thus over the course of semester, students work in three different lab groups.

ABET Assessment Objectives

This course satisfies a number of ABET outcomes. For purposes of ABET accreditation, three outcomes are assessed at the end of each semester. ABET outcomes catered through this course are as follows: (Assessed outcomes are indicated)

- An ability to apply knowledge of mathematics, science and engineering;

- An ability to function in multidisciplinary teams; (Assessed Outcome)
- An ability to identify, formulate and solve engineering problems;
- An ability to communicate effectively; (Assessed Outcome)
- An ability to use the techniques, skills and modern engineering tools necessary for engineering practice;
- An ability to apply mathematics through differential equations; probability and statistics; calculus-based physics; general chemistry; and geology
- An ability to apply knowledge in the following four recognized major civil engineering areas: structural engineering, geotechnical engineering, transportation engineering, water resources engineering with a depth of focus in one or more of the four areas;
- An ability to conduct laboratory experiments and to critically analyze and interpret data in the following four (4) recognized major civil engineering areas: structural engineering, geotechnical engineering, transportation engineering, water resources engineering; (Assessed Outcome)
- An ability to apply knowledge of sustainability to civil engineering practice.

Assessment matrices were developed for all three assessed outcomes. The subsequent sub-sections discuss the evaluation methods for each of these.

Outcome: Ability to Function in Multidisciplinary Teams

The evaluation of a student's ability to function in a multidisciplinary team is a challenging problem from an instructor's perspective. In order to conduct quantitative evaluation a peer review system was chosen. After review of various peer review procedures, the web-based evaluation system called Comprehensive Assessment of Team Member Effectiveness (CATME) was selected. The CATME system was specifically developed with the assessment objective of "ability to function in multidisciplinary team" in mind(1). Extensive validation studies have also been conducted for this system(2).

The assessment of this objective was conducted for the second set of lab student groups which included a total of five laboratory sessions and preparation of one comprehensive report. Students are asked to conduct peer evaluations of their group mates using the CATME tool during the course of these labs and corresponding report preparation. In order to minimize the effects of "first time use", students were asked to conduct similar evaluations for their first lab group. The CATME evaluation of each student by their peers also has an effect on their lab report score; it is 10% of their lab report grade.

The specific objectives evaluated for this outcome are same as those evaluated by the CATME system. These include:

- Contributing to team’s work;
- Interacting with teammates;
- Keeping the team on track;
- Expecting quality; and
- Having related knowledge, skills and abilities.

For each of the above objectives the CATME system has five score levels. Each student scores himself/herself as well as his/her group mates. Table 1 shows the evaluation matrix, the expected score level for each objective is also shown. The baseline scores considered acceptable are shown shaded in gray.

Outcome: Ability to Communicate Effectively

This course focuses on the technical reporting component of effective communication skills. Students’ outcome is determined by evaluating a series of objectives that represent technical writing skills. The objectives and their brief description are as follows:

- Grammatically Correct Writing: Students should be able to write in grammatically correct manner with complete sentences and use of consistence tense throughout the write-up. This objective is evaluated for the second lab report submitted by students. The evaluation is conducted for write-up on aggregate specific gravities.
- Technical Writing Skills: Students should be able to describe technical matter effectively. Correspondingly students are asked to describe the laboratory experimental procedure for measurement of aggregate specific gravity and absorption. The expectation is that students explain the procedure in technically sound manner with use of passive and indirect voice.
- Presentation of Experimental Results: Students should be able to present the experimental data in efficient manner through use of table or charts. The results should be presented without ambiguity and in correct format. The evaluation of this objective is done through second lab report, specifically in terms of presentation of experimental data from Vicat test result for initial setting time of Portland cement.
- Technical Report Format: Students should be able to develop a technical report that has appealing and professional format. Such report should include: use of proper heading system, inclusion of page numbers, provision of table of contents, numbered figure titles, and numbered table titles. Once again this objective is also evaluated through the second lab report.

A scoring system was developed to quantify each of the above objectives. Table 2 shows the scoring system along with acceptable baseline scores that were established for each.

Table 1: Evaluation Matrix for ABET Outcome of "Ability to Function in Multidisciplinary Teams" (objective description from Ohland et al., 2004)

Score	Contributing to Team's Work	Interacting with Teammates	Keeping the Team on Track	Expecting Quality	Having Related Knowledge, Skills, and Abilities
5	Does more or higher-quality work than expected. Makes important contributions that improve the team's work. Helps teammates who are having difficulty completing their work.	Asks teammates for feedback and uses their suggestions to improve. Provides encouragement or enthusiasm to the team. Makes sure teammates stay informed and understand each other. Asks for and shows an interest in teammates' ideas and contributions.	Watches conditions affecting the team and monitors the team's progress. Makes sure that teammates are making appropriate progress. Gives teammates specific, timely, and constructive feedback.	Motivates the team to do excellent work. Cares that the team does outstanding work, even if there is no additional reward. Believes that the team can do excellent work.	Demonstrates the knowledge, skills, and abilities to do excellent work. Acquires new knowledge or skills to improve the team's performance. Able to perform the role of any team member if necessary.
4	Demonstrates behaviors described above and below.	Demonstrates behaviors described above and below.	Demonstrates behaviors described above and below.	Demonstrates behaviors described above and below.	Demonstrates behaviors described above and below.
3	Completes a fair share of the team's work with acceptable quality. Keeps commitments and completes assignments on time. Helps teammates who are having difficulty when it is easy or important.	Respects and responds to feedback from teammates. Participates fully in team activities. Communicates clearly. Shares information with teammates. Listens to teammates and respects their contributions.	Notices changes that influence the team's success. Knows what everyone on the team should be doing and notices problems. Alerts teammates or suggests solutions when the team's success is threatened.	Encourages the team to do good work that meets all requirements. Wants the team to perform well enough to earn all available rewards. Believes that the team can fully meet its responsibilities.	Demonstrates sufficient knowledge, skills, and abilities to contribute to the team's work. Acquires knowledge or skills as needed to meet requirements. Able to perform some of the tasks normally done by other team members.
2	Demonstrates behaviors described above and below.	Demonstrates behaviors described above and below.	Demonstrates behaviors described above and below.	Demonstrates behaviors described above and below.	Demonstrates behaviors described above and below.
1	Does not do a fair share of the team's work. Delivers sloppy or incomplete work. Misses deadlines. Is late, unprepared, or absent for team meetings. Does not assist teammates. Quits if the work becomes difficult.	Is defensive. Will not accept help or advice from teammates. Complains, makes excuses, or does not interact with teammates. Takes actions that affect teammates without their input. Does not share information. Interrupts, ignores, bosses, or makes fun of teammates.	Is unaware of whether the team is meeting its goals. Does not pay attention to teammates' progress. Avoids discussing team problems, even when they are obvious.	Satisfied even if the team does not meet assigned standards. Wants the team to avoid work, even if it hurts the team. Doubts that the team can meet its requirements.	Missing basic qualifications needed to be a member of the team. Unable or unwilling to develop knowledge or skills to contribute to the team. Unable to perform any of the duties of other team members.

Table 2: Evaluation Matrix for ABET Outcome of "Ability to Communicate Effectively"

Score	Number of Writing Errors	Technical Writing Skills	Presentation of Experimental Data	Technical Report Format
4	All sentences are grammatically correct, complete and with correct structure.	Experimental procedure is correctly described in concise, non-repetitive and proficient manner with use of correct voice.	Vicat test (initial setting time) data is presented in efficient and clear manner through use of table and/or figure.	Report includes: Page numbers, table of contents, well-defined heading system, figure titles, table titles.
3	Between 1 and 3 sentences are grammatically incorrect, incomplete or lacking proper structures.	The correct experimental procedure is conveyed in legible manner, but there is lack of conciseness and proficiency. (Minor deviations from good technical writing.)		One of the format items are missing.
2	Between 3 and 6 sentences are grammatically incorrect, incomplete or lacking proper structures.	The correct procedure is conveyed in legible manner, but there is significant lack of conciseness and proficiency. (Significant deviations from good technical writing)	Vicat test (initial setting time) data is presented in an inefficient and/or unclear manner.	Two format items are missing.
1	Between 6 and 9 sentences are grammatically incorrect, incomplete or lacking proper structures.	The experimental procedure is conveyed in ambiguous manner.		Three format items are missing.
0	More than 9 sentences are grammatically incorrect, incomplete or lacking proper structure.	The experimental procedure is conveyed incorrectly.	Test data is not presented.	Four of more format items are missing.

Table 3: Evaluation Matrix for ABET Outcome of "Conduct Laboratory Experiments and to Critically Analyze and Interpret Data"

Score	Reported Lab Procedure	Data Collection	Data Analysis	Measurement Accuracy	Theoretical Interpretation	Data Interpretation and Recommendation
3	Lab procedure is correctly reported. Any deviations from ASTM procedure are clearly indicated in report.	All three measured weights are reported. Weights follow generally observed trend.	All three properties are correctly evaluated using measured data.	Measured gravity is within 0.1 of actual value	Derivation is correctly shown for both dry and SSD bulk specific gravities.	Data is correctly interpreted (high slump = high workability). Recommendations are made for changing workability.
2	Lab procedure is correctly reported, however deviations from the ASTM specifications are not stated in report.	All three measured weights are reported. Weight data is inconsistent. (Example Dry Weight > SSD Weight)	Two out of three properties are correctly evaluated.	Measured gravity is between 0.1 and 0.2 of actual value	Derivation is correctly shown for dry and SSD bulk specific gravities. Some derivation steps are missing.	Data is correctly interpreted. No recommendations are made.
1	Incorrect lab procedure is reported, with at least 1 important step eliminated.	At least one weight measurement is not reported.	One property is correctly evaluated.	Measured gravity is between 0.2 and 0.5 of actual value	Partial derivation is shown (correct approach is used but derivation is not complete)	Data is correctly interpreted. Incorrect recommendations are made.
0	Lab procedure is not reported.	All measurements are not reported.	No properties are correctly evaluated.	Measured gravity deviates more than 0.5 of actual value	Derivation is incorrect or not shown.	Data is incorrectly interpreted.

Outcome: Ability to Conduct Laboratory Experiments and to Critically Analyze and Interpret Data

The title of the outcome is self-explanatory as far as the objective of this component of assessment. In order to conduct the assessment once again a number of objectives were developed and quantitatively evaluated. The assessment objectives, their brief description and procedure for evaluation are as described below:

- Reported Lab Procedure: Students should be able to follow the ASTM specified lab procedures for conducting experiments. This objective is evaluated using ASTM C127 specifications for determining the specific gravity of coarse aggregate. The evaluation is conducted by comparing the reported procedures used by students with the actual ASTM specified procedure.

- Data Collection: Students should be able to correctly collect data required for evaluation of a material property. Data collection should be done with procedures indicated in ASTM specifications. This objective is also evaluated using coarse aggregate specific gravity test specified as ASTM C127.

- Data Analysis: Students should be able to correctly determine the material properties using experimentally collected data. Similar to above objectives the ASTM C127 procedure for determining specific gravity of coarse aggregate was used.

- Measurement Accuracy: Students should be able to accurately determine the bulk (dry) specific gravity of coarse aggregate sample by following the ASTM C127 test procedure. The specific gravity provided by the aggregate manufacturer was utilized as the value for comparison. The manufacturer's results were cross-checked by instructor and teaching assistant to ensure the correctness.

- Theoretical Interpretation of Lab Procedure and Analysis: Students were asked to demonstrate that experimentally determined bulk specific gravities (dry and SSD) calculated using various weights (dry, SSD, and submerged) match the theoretical definitions of the specific gravities for coarse aggregate.

- Data Interpretation: Students should be able to correctly interpret the experimental findings and provide recommendations based on the findings. This objective is evaluated using PCC workability results evaluated using slump cone method specified as ASTM C-143 procedure.

Table 3 shows the scoring matrix for this outcome. For each of the objectives described above different baseline acceptable levels were established. These are also shown on the table (shaded in gray).

ABET Assessment Results

This section presents the results for three assessed ABET outcomes as described in previous sections. The results are reported for fall 2010 and spring 2011 semesters. Figure 1 shows the average of the each outcome as well as the baseline values. Please note that in order to make fair comparison all values are converted to percentages. It can be seen from the results that for fall 2010 semester the student performance exceeded the baseline expectations on an averaged basis. This is also true for first two outcomes during spring 2011, however for the outcome that evaluates ability of students to conduct experiments and critically analyze and interpret the data, the scores are about 20% below the anticipated baseline on averaged basis. It should also be noted that during the spring semester there were considerably smaller number of students in the course as compared to fall 2010 (12 versus 34).

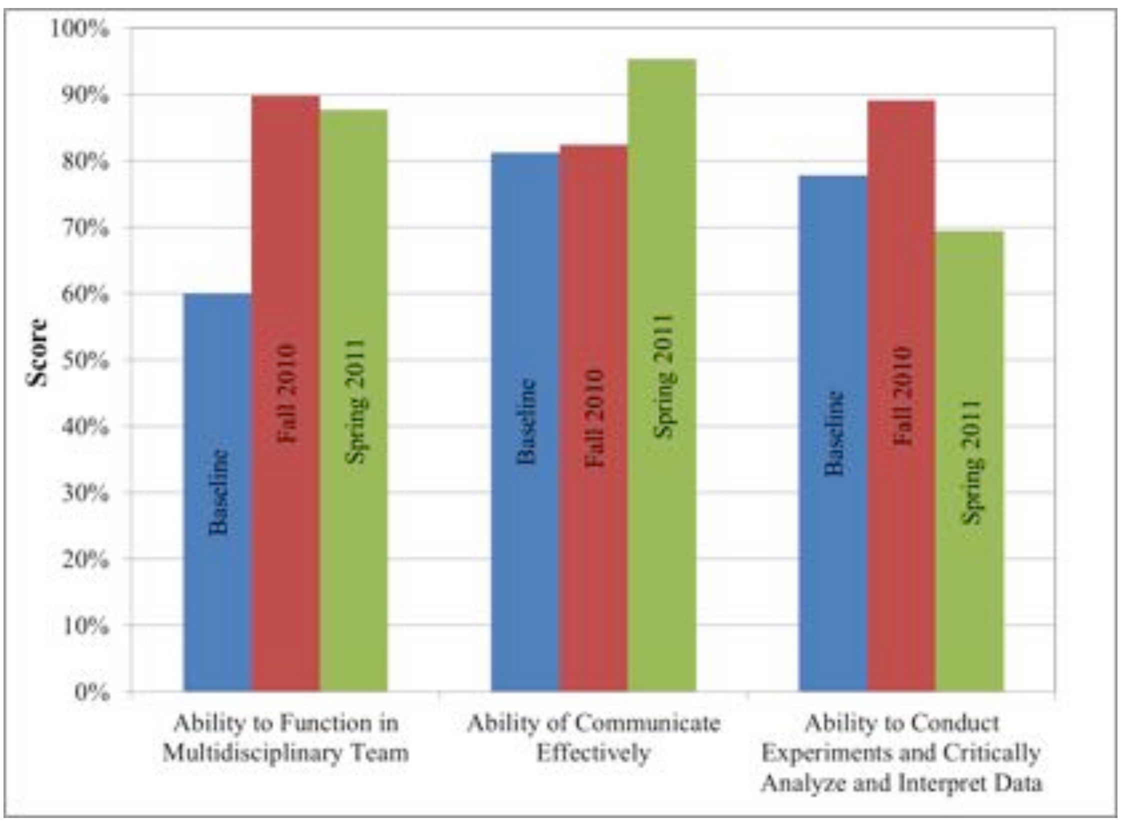


Figure 1: Average Scores for Each Assessed Outcome (Acceptable Baseline, Fall 2010 and Spring 2011 are shown).

The assessment data collected from the two semesters is also analyzed to determine what percentage of students are meeting and exceeding the baseline requirements. This data is presented in Figure 2. The results show that the students have very good capability to effectively work in multidisciplinary teams. From written communications perspective, the results show significant improvement in spring 2011 semester as compared to fall 2010. This is partly due to added efforts by the instructor to provide good samples of technical writing as well as spending approximately half lab session to give good technical writing tips to the students. The results also show that during fall 2010 students exhibited good ability to conduct experiments and to analyze and interpret the experimental findings. The results from spring 2011 were not satisfactory in this aspect with 50% students not meeting the baseline expectations. A detailed look at the raw data indicated that the main shortcomings were from "measurement accuracy" and "theoretical interpretation" point of view. In future semesters more emphasis will be given to these aspects. In particular teaching style will be slightly modified as well as additional discussions will be added.

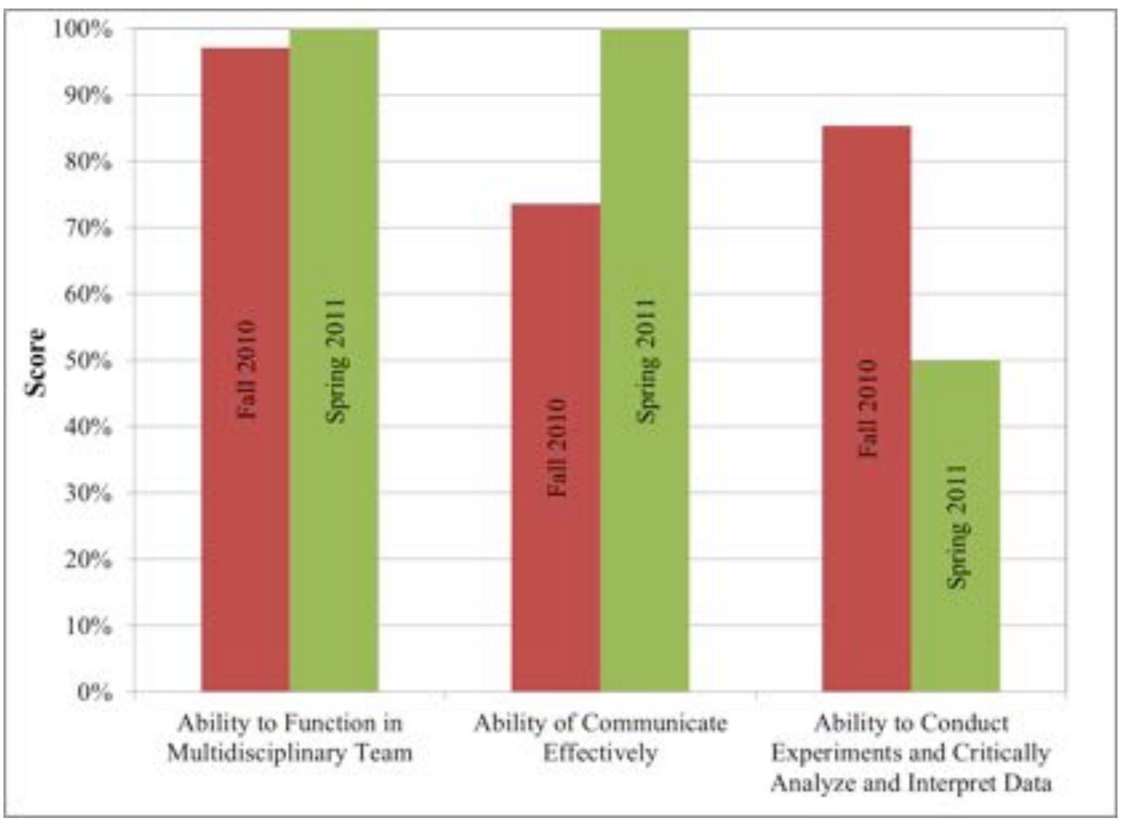


Figure 2: Percent Students Meeting and Exceeding the Baseline Requirements.

Summary

This paper describes the development of "Infrastructure Materials" course at University of Minnesota Duluth. The paper briefly describes the course objectives, syllabus topics and course organization. The second half of the paper describes the development and assessment methods for three ABET outcomes evaluated through this course. The evaluation results for first two semesters are also presented. Based on the assessment results it was observed that improvement is needed to increase the ability of students to conduct experiments and critically analyze and interpret data.

References

(1) Ohland, M.W., R.A. Layton, M.L. Loughry, and A.G. Yuhasz, "Effects of Behavioral Anchors on Peer Evaluation Reliability," Journal of Engineering Education, 94(3), July 2005, pp. 319-326.

(2) Ohland, M.W., M.L. Loughry, R.L. Carter, and A.G. Yuhasz, "Designing a Peer Evaluation Instrument that is Simple, Reliable, and Valid" Proceedings of the American Society of Engineering Education Annual Conference, Salt Lake City, Utah, June 2004, session 1526.

Biographical Information

ESHAN V. DAVE

Eshan Dave is assistant professor in the Civil Engineering department at the University of Minnesota Duluth. Prior to his current appointment, Dr. Dave was post-doctoral research associate and instructor at the University of Illinois at Urbana-Champaign.

Project Cam-A-Rok, Engaging Mechanical Engineering Freshman

William C. Farrow
Mechanical Engineering Department, Milwaukee School of Engineering, 1025 N Broadway, Milwaukee, WI 53202

Introduction

This paper documents the implementation of many of the leading concepts into a successful freshman design course. There are many different forms that a freshman introductory engineering design course can take, and many examples shared through publication that describe what has worked. The experience outlined combines benefits of both a team-centric as well as an individual centric course. It contains both project driven aspects as well as short term homework style assignments. And the course completes the design work through both a virtual implementation in a solid modeling environment as well as a hands-on fabrication of the final design. Although this implementation involved model rockets as the basis of the project, the course could easily be adapted to other projects of a similar size.

Background

Taking advantage of the pedagogical work that has been done in exploring the freshman engineering design experience, this course was developed by implementing aspects and techniques that have been shown to enhance engineering student's learning as well as reinforces their interest and excitement. Sheppard and Jenison documented a strategy for describing the Organizational Framework of a course by identifying the skill (content) and process (how) of what is to be learned. [(1)] Four quadrants were described: Individual Content, Team Content, Individual Process, Team Process and how they differ in the learning process. Sheppard and Jenison then applied their Organizational Framework to study freshman engineering courses at a number of different institutions. [(2)] Their key conclusion might be summarized as an institution should chose the quadrants for freshman learning based on what fits at that institution, but should work to insure that students experience learning in all 4 quadrants as they continue through their curriculum.

Drummond as well as Knight, et al, describe the value of Team Based Learning (TBL) in both in the classroom as well as outside. [(3)(4)] Work done by Ohland, et al, demonstrates the value of cultivating the team experience, especially with team member/peer feedback during the process. [(5)] Layton, et al, have further enhanced the process by developing a software based tool called CATME that effectively coordinates the peer feedback. [(6)]

The virtues of Problem Based Learning (PBL) in an engineering course have been described by Kellar, et al, though they do warn that PBL implementation requires great deal of coordinated time and effort. [(7)] Mills and Treagust further describe the difference between Problem Based Learning and Project based learning. [(8)] Simply put, a project can be thought of as the compilation of a number of smaller problems. So, Project Based Learning builds on Problem Based learning by assembling an overarching structure to help break the project down into workable problems.

Finally, Knight, et al, as well as Barr, et al, describe the ability for students to gain experience with their learning through hands on exercises. [4] [9] Knight, et al, describes where a number of different freshman projects that required the students to actually build their designs led to better retention of those students in their original course of study. Whereas Barr, et al, describe how a hands on Reverse Engineering project helped to their students to better understand the design process and the critical nature of assembling multiple parts into a whole system.

Basic Structure of the Course

The course developed is for an 11 week quarter that has a 1 hour lecture meeting twice each week and a 2 hour lab session each week. Within that structure, the students are learning principles of engineering design and developing solids modeling techniques. Based on the background work, it was decided that the course should incorporate both team content as well as individual content, and it should work to develop engineering design skills as well as foster the teaming process. In addition, the work should include a hands-on aspect, this may be implemented in the form of a reverse engineering aspect to a portion of the project, or may even include the fabrication of the final design.

This was achieved by implementing a course long project that is worked by student teams. In addition to the main project, there are a number of incremental problems to be solved, some take the form of individual homework problems, while others require the full teams attention. The teams were assigned during the first week using the CATME [6] software's survey feature that allows students to input information about their preferences. Team members were collocated in the classroom allowing them to work together on team specific assignments and to support each other on in class learning exercises. Team building exercises are included in the first couple of weeks, and teaming is fostered throughout the quarter by the nature of the class time. For example, when working on in-class learning exercises, team members are expected to seek insight from their team to answer a question before asking the course instructor. This simple task has helped make team members more likely to seek each other when issues arise in the process of solving more complex parts of the project.

Formative assessment includes individual as well as team homework problems, and individual quizzes throughout the quarter. Many of both the individual and team homework problems are pulled from aspects of the overall design project, giving them a "guided tour" of the design process as they work their way to a final design. Summative assessment takes the form of team presentations, a team design report and an individual final exam. In addition to the grades that are earned, there is usually a "fun" bonus aspect to the project for all the teams that complete incremental work as well as the final design.

Project "Cam-A-Rok" the Selected Design Project

A project was needed that would lend itself to 10 weeks of student team effort, give opportunity to demonstrate the engineering design process, allow for solids modeling assignments, be enhanced by teaming studies and require hands-on interaction in both a reverse engineering aspect as well as in design fabrication. The project selected was Project “Cam-A-Rok”; a project to design a payload module that would carry a digital camera on a model rocket allowing for in-flight filming of video.

The identified need for this device was stated as:

> "A model rocket company needs a payload module that can carry a specific digital camera on a model rocket in a way that will allow the camera to film the ground beneath the rocket as it flies skyward." (Figure 1)

Figure 1 Concept for "Cam-A-Rok" Project

Subject to the constraints:

- Must not alter the camera in any way.
- Must be capable of filming (video) looking down past the tail of the rocket as it flies.
- Must allow the camera to be easily removed and reinserted.
- Must allow for the activation of the mode button, the shutter release button and view of the LCD display for mode confirmation while on the launch rod.
- Must be such that together all of the parts of the payload module will fit within a 3.5 x 3.5 x 7 inch volume (total rapid prototype volume available for each team).
- Must be safe for a typical college student to operate.

Each team was supplied with a “Design Support Kit” that included all the materials and equipment necessary for the reverse engineering of the rocket as well as the fabrication of the Cam-A-Rok system. The components included in the Design Support Kit are listed in Table 1 and can be seen in Figure 2.

Table 1 Design Project Support Kit Parts List

Item No.	Description
1	Project Case

<table>
<tr><td>2</td><td>Camera Kit
<table>
<tr><th></th><th>Item No.</th><th>Description</th></tr>
<tr><td>☐</td><td>2.1</td><td>Digital Camera – VistaQuest VQ1005</td></tr>
<tr><td>☐</td><td>2.2</td><td>SD Memory Card – Lexar 512 MB</td></tr>
<tr><td>☐</td><td>2.3</td><td>AAA Battery</td></tr>
<tr><td>☐</td><td>2.4</td><td>Camera Specification Card</td></tr>
<tr><td>☐</td><td>2.5</td><td>Camera Quick Start Guide</td></tr>
<tr><td>☐</td><td>2.6</td><td>Large Mirror Tile – 0.75 in. x 0.75 in.</td></tr>
<tr><td>☐</td><td>2.7</td><td>Small Mirror Tile – 0.375 in. x 0.375 in.</td></tr>
</table>
</td></tr>
<tr><td>3</td><td>Model Rocket Kit – ModelRockets.us Centauri</td></tr>
<tr><td>4</td><td>Digital Caliper – Fowler Model #54-101-150</td></tr>
<tr><td>5</td><td>Execl Hobby Knife</td></tr>
<tr><td>6</td><td>12” Stainless Steel Ruler</td></tr>
<tr><td>7</td><td>9 in. x 12 in. Self-healing Cutting Mat</td></tr>
</table>

Figure 2 Design Project Support Kit Contents

Along the way, individual assignments concentrated more on developing the students’ skills with the solids modeling software, while the team assignments aligned with the design process.

Individual assignments included:

- Simple orthographic and perspective engineering sketching
- Various techniques for generating parts in the solids modeling software

- Generating flat drawings with correct dimensioning and tolerancing from the solid models
- Assembling the solid model parts into assemblies
- Simple reverse engineering strategies implemented on the model rocket kit and the exterior of the digital camera

The team assignments involved:

- Thoroughly identifying the problem need, the constraints and design criteria.
- Brainstorming possible solutions to the problem
- Evaluating the solution ideas
- Implementing the selected solution idea as a solid model with tolerances required to allow for Additive Manufacturing Rapid Prototyping techniques.
- Presenting their teams "trek" through the design process to the class
- Fabricating their rocket, finishing their model returned from the Rapid Prototyping Process, and testing its ability to allow the camera to function
- Formal Presentation to class on the team's final design result and its functionality
- Design report and portfolio documenting all the work done throughout design process

The final aspect to the project, the "fun" bonus for completing all the incremental work required by the design process, was the chance to "fly" their rocket and put their design to the test. "Launch Day" for the teams that had all the work completed and turned in was the last Saturday before final exams. With the assistance of a couple of upperclassmen, we all went out to the athletic fields and one by one flew all of the designs.

Results – The Student Designs and Flights

Figure 3 Examples of Design Teams' Resulting Solid Models

A sampling of the models resulting from the student teams is shown in

Figure 3. They took on two general configurations, a vertical orientation of the camera with the lens pointed to the side using a mirror to see downward, and a horizontal camera orientation with the lens pointed downward through a hole in the capsule.

All of the teams completed all of the incremental work required and were able to participate in the bonus Launch Day activity. An example of the launch and flight can be seen in Figure 4.

Figure 4 Rockets In Flight

A total of 12 teams with 4 students per team were involved with project. All 12 teams flew their rockets, with varying levels of success. The fabrication skills varied greatly across the teams resulting in a range of performance from some models that "jammed" on the guide rail during liftoff, to rockets that did not successfully deploy their parachutes to models that performed flawlessly returning with video footage of the flight. Of the 12 teams, 5 teams captured video, Figure 5 shows a sampling of still frames from some of the clearer video footage shot on the successful flights.

Conclusion

Neither the formative nor summative assessment showed significant improvement over previous courses, but even though the learning environment was much more relaxed the class was able to cover more material than it had in the past. Most of the teams developed a level of camaraderie usually seen in sports teams. Aspects that I plan to improve on in the future include allowing the students to use the CATME feedback surveys on two week intervals rather than four week intervals and to develop additional projects that would fit the same format.

Acknowledgments:

- Wisconsin Space Grant Consortium – Higher Education Incentives Seed Grant, that supported the purchase of the supplies used in the project.
- Milwaukee School of Engineering Rapid Prototype Consortium – Manufacturing the RP models pro bono.

Figure 5 Samples from Successful "Cam-A-Rok" Videos

References

1. *Thoughts on Freshman Engineering Design Experiences.* **Sheppard, Sheri and Jenison, Rollie.** 1996, 26th ASEE/IEE Frontiers in EducationConference Proceedings, pp. 909-913.
2. *Examples of Freshman Design Education.* **Sheppard, Sheri and Jenison, Rollie.** 1997, International Journal of Engineering Education Vol. 13, No. 4, pp. 248-261.
3. *Team-Based Learning to Enhance Critical Thiinking Skills in Entrepreneurship Education.* **Drummond, Colin.** 2, Las Vegas : s.n., 2010, Proceedings of the Academy of Entrepreneurship, , Vol. 16, pp. 18-22.
4. *Staying in Engineering: Impact of a Hands-On, Team-Based, First-Year Projects Course on Student Retention.* **Knight, daniel, Carlson, Lawrence and Sullivan, Jacquelyn.** 2003, Proceedings of the 2003 ASEE Annual Conference & Exposition.
5. *The comprehensive Assessment of Team Member Effectiveness: A New Peer Evaluation Instrument.* **Ohland, Matthew, Pomeranz, Hal and Feinstein, Harlan.** 2006, ASEE Anual Conference Proceedings.
6. *Software for Sudent Team Formation and Peer Evaluation: CATME Incorporates Team-Maker.* **Layton, Richard, Ohland, Matthew and Poneranz, Hal.** 2007, ASEE Annual Conference Proceedings.
7. *A Problem Based Learning Approach for Freshman Engineering.* **Kellar, Jon, et al.** October 2000, 30th ASEE/IEEE Frontiers in Education Conference Proceedings, pp. F2G-7 - F2G-10.
8. *Engineering Education - Is Problem-Based or Project-Based Learning the Answer?* **Mills, Julie and Treagust, David.** Australasian Journal of Engineering Education.
9. *An Introduction to Engineering Through an Integrated Reverse Engineering and Design Graphics Project.* **Barr, Ronald, et al.** October 2000, Journal of Engineering Education, pp. 413-418.

Biography

WILLIAM C. FARROW has been teaching at the Milwaukee School of Engineering full time for 10 years in the Mechanical Engineering department. Besides teaching courses related to engineering design and engineering mechanics he works with students pursuing aerospace career goals. Dr. Farrow has worked for McDonnell Aircraft Comp., Eaton Corporation's Corporate Research Division, and at NASA's Jet Propulsion Lab as a Faculty Research Fellow.

Fuzzy Versus Conventional Control

Marian S. Stachowicz,
Laboratory for Intelligent Systems, Department of Electrical and Computer Engineering,
University of Minnesota, USA,
The Warsaw School of Computer Science, Warsaw, Poland
mstachow@d.umn.edu

Abstract

This article presents notes from the interdisciplinary course ECE 5831 Fuzzy Sets Theory and Its Applications and an introduction part to ECE 4951 Design Workshop dedicated to Intelligent Control, both taught at the ECE Department, University of Minnesota Duluth. What are the advantages and disadvantages of fuzzy control as compared to conventional control? What are the perspectives of conventional control engineers on fuzzy control? In this paper we will attempt to give answers to these questions by asking, and at least partially answering, a series of questions that we have accumulated over the years from a variety of engineers in industry and universities concerned about whether to use fuzzy or conventional control.

1. Introduction

Two approaches are available for study of conventional control systems [13], [14]. The first is known as the classic technique. This technique is based on converting a system's differential equation to an algebraic equation and to a transfer function. The primary disadvantage of the classical technique is its limited applicability. It can be applied only to linear, time-invariant system. A major advantage is that they rapidly provide stability and transient response information. The second is the state space approach. This technique is a unified method for modeling, analyzing, and designing nonlinear and time-varying system. This approach can be applied for a wide range of systems, including the same group modeled by the classical approach however the state-space technique is not as intuitive as the classical approach. The designer has to engage in several calculations before the physical interpretation of the model is apparent.

In our educational program for undergraduate students, the coverage of both conventional approaches are limited to linear, time-invariant systems or systems that can be linearized using Taylor series and it is a subject of ECE 2111 Signal and Systems and ECE 3151 Control Systems courses. Leonhard Euler (1707-1783), Jean Baptiste Joseph Fourier (1768-1830), Pierre Simon Laplace (1749-1827) dominant in these courses [12].

The study of other classes of systems could be presented on an elective three credit ECE 5831 Fuzzy Sets Theory and Its Applications or on required four credits ECE 4951 Design Workshop-Intelligent Control course.

In conventional control deliver during ECE 3151 Control Systems, required three credit course, the prime desiderata are precision, certainty, and rigor. By contrast, the point of departure in fuzzy control in ECE 5831 Fuzzy Sets Theory and Its Applications is the thesis that precision and certainty carry a cost and that control should exploit the tolerance for imprecision and uncertainty [13]. The exploitation of the tolerance for imprecision and uncertainty underlies the remarkable human ability to understand distorted speech, summarize text, recognize and classify images, drive a vehicle in dense traffic and, more generally, make rational decisions in an environment of uncertainty and imprecision. In effect, fuzzy control uses the human mind as a role model. A fuzzy sets theory is an important part of the intelligent control.

It is now realized that complex real-world problems require intelligent systems that combine knowledge, techniques, and methodologies from various sources. These intelligent systems are supposed to posse's humanlike expertise within a specific domain, adapt themselves and learn to do better in changing environments, and explain how they make decisions or take actions. As opposed to PID, lead-lag, and state feedback control where the focus is on modeling and the use of this model to construct a controller that is described by diff erential equations, in fuzzy control we focus on gaining an intuitive understanding of how to best control the process, then we load this information directly into the fuzzy controller.

2. Fuzzy Sets Theory

As Professor Lotfi A. Zadeh from University of California, Berkeley, pointed out in 1965 in his seminal paper entitled "Fuzzy Sets" such imprecisely defined sets or classes "play an important role in human thinking, particularly in the domains of pattern recognition, communication of information, and abstraction". Note, that the fuzziness does not come from the randomness of the constituent members of the sets, but from the uncertain and imprecise nature of abstract thoughts and concepts. The main contribution of fuzzy logic is a methodology for computing with words [3], [7], [9]. A key aspect of computing with words is that it involves a fusion of natural languages and computation with fuzzy variables. A selection of fuzzy if-then rules forms the key component of fuzzy inference system that can effectively model human expertise in specific applications. Because of its multidisciplinary nature, the fuzzy inference system is known also by other names, such as fuzzy expert system, fuzzy-rule-based system, fuzzy associative memory, fuzzy system, and fuzzy logic controller (Fig.1).

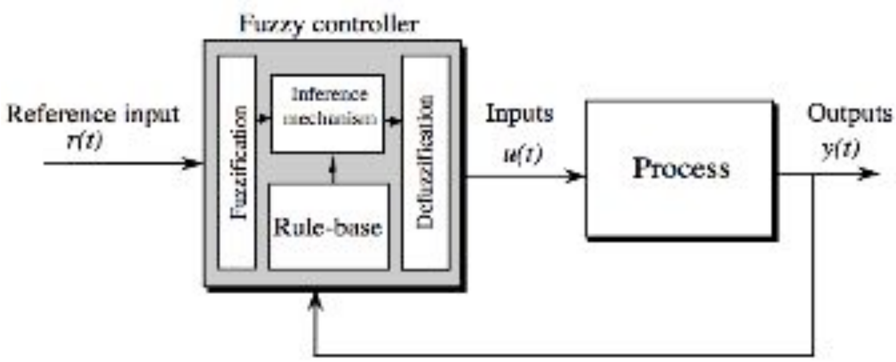


Fig. 1. Fuzzy logic controller

Professor L.A. Zadeh introduced initial ideas of fuzzy control explicitly in 1972, the actual research on fuzzy controllers was started by Professor Mamdani and his students at Queen Mary College in London in the mid -1970s. According to the literature, the first commercially available fuzzy controller for cement kilns was developed by I. P. Holmblad and K. J. Ostergaard in 1982. An automatic-drive fuzzy control system for subway trains in Sendai City (1987) was extremely successful. It is generally praised as superior to other comparable systems based on classical control. The fuzzy controller achieves not only a higher precision in stopping at any designated point, but makes each stop more comfortable; in addition, it saves about 10% of energy. A complete list of other industrial projects, including control problems that are considered beyond the capabilities of classical control theory, that employ fuzzy control would be too long. Fuzzy controllers have also been installed with great success in variety of consumer products, including TV sets, video cameras, vacuum cleaners, washing machines, automobiles (antiskid brake systems, automatic transmissions) and many others [10], [11].

3. Objectives ECE 5831 Fuzzy Sets Theory and Its Applications course

This forty-five hours interdisciplinary course provides the comprehensive treatment of the constituent methodologies underlying fuzzy set theory, an evolving branch within the scope of computational intelligence that is drawing increasingly more attention. In particular, course put equal emphases on theoretical aspects of covered methodologies, as well as some empirical observations and verifications of various applications in practice. The problems in this course are based on current and potential applications in disciplines of computer science, electrical engineering, mechanical engineering, biomedical engineering, medicine, and business.

4. Objectives ECE 4951 Design Workshop course

In this workshop no formal lectures were taught. However the students received an intensive review covering the topics of the 68HC12 microcontroller [6], sensors, and twelve hours lectures and three labs related to Fuzzy Logic Control [5]. During this workshop, the students worked in small groups and were required to design, build and program the controller with intelligent behaviors using fuzzy logic. The Problem Based Learning (PBL) principles [1], [2], [3] were applied. As results, students obtained specific technical knowledge, got group work and managing the project experience as well as presenting the poster and final report. It improved also their communication skills.

Fuzzy Logic has emerged as a practical alternative that provides a convenient method to implement nonlinear controllers. Fuzzy controllers work differently than conventional controllers; expert knowledge is used instead of differential equations to describe a system. This knowledge can be expressed in a very natural way using linguistic variables, which are described by fuzzy sets. Fuzzy Logic has been used primarily on large-scale computing systems and personal computers. The technology involved in intelligent and fuzzy systems is of such a fundamental nature that in 21 century it will be standard knowledge for all engineers and scientists. Overall, in comparing fuzzy to conventional control, it is interesting to note that there are conventional control schemes that are analogous to fuzzy ones:

1. Direct fuzzy control is analogous to direct nonlinear control,

2. Fuzzy adaptive control is analogous to conventional adaptive control (e.g., model reference adaptive control), and

3. Fuzzy supervisory control is analogous to hierarchical control.

Does there exist an analogous conventional approach to every fuzzy control scheme? If so, then in doing fuzzy control research it seems to be very important to compare and contrast the performance of the fuzzy versus the conventional approaches.

The introduction of Motorola's MC68HC12 microcontroller, which incorporates several Fuzzy Logic primitives in its instruction set, has made possible the implementation of fuzzy controllers in microprocessor-based systems [5], [6], [7], [8].

5. Final Results

Following projects of the ECE 4951-Spring-2010 Design Workshop: Intelligent Control Design Using S12 Microcontroller were presented successfully by students during 15th Annual UMD Undergraduate Research/Artistic Showcase (speech and posters presentations, hardware demonstrations), Kirby Ballrooms, UMD, April 29, 2010 as well as posters presentation in Minnesota Power, Headquarter, Duluth, April 30 - May 7, 2010. Dr. Christopher Carroll and Dr. Marian S. Stachowicz from ECE Department, UMD, conducted this workshop.

1. Matthew Wright and Andrew Pedersen,
Intelligent Wallet
2. Jared Sweet and Michael Phillips,
Intelligent Greenhouse Control
3. Alex Kamrud and Nic Westing,
Color Recognition for Tracking Robots
4. Emily Hamilton and Derrick Keffeler,
Path Tracking Vehicle with Fuzzy Control
5. Chris Pflepsen and Stephen Cheruiyot,
Voice Controlled Lights
6. Mark Bretall and Joe Engebretson,
Voice Activated Control of a Direct Current Motor
7. Andrew Becklund and Robert Yang,
Intelligent Helmet – Threat Detection

6. Conclusions

During four years that we have been offering the Design Workshop course on intelligent systems we have found that students were more motivated in the learn fuzzy set theory and microcontroller programming by applying them to the design and implementation to real problems. We could say that students gained an excellent understanding of the both topics of microcontrollers and fuzzy logic control. The workshop was organized in such way that students worked during whole semester on their projects. Students were exposed to teamwork, managing the project and had the opportunity to improve their written and oral communication skills. We should view the fuzzy controller as an artificial decision maker that operates in a closed-loop system in real time. The more students understand conventional control, the more they will be able to appreciate some fine details of the operation of fuzzy control system.

The future improvements to the Design Workshop course will be through addition the following aspects: multidisciplinary teams including students from different engineering departments, for example, from electrical, mechanical, industrial or computer science. The students also should address in the final reports the environmental, ethical, and economical issues that would be affected by their projects. Furthermore the project work should be created using principle of the Problem Based and Project Organized Learning with concrete goals and criteria. Fuzzy set theory will inevitably play important role in any problem area that involves natural language.

7. References

[1] L. B. Kofoed & S. Hansen, Teaching process competences in a PBL curriculum.
In: *Kolmos, A. et all (eds.)The Aalborg Model: Progress, Diversity and Challenges.*
Aalborg University Press,2004.

[2] L. B. Kofoed & F. Jørgensen, Using Problem Based Learning Methods from Engineering Education in Company Based Development. *Proceedings of the 18th Conference of the Australasian Association for Engineering Education*. Melbourne : Department of Computer Science and Software Engineering, The University of Melbourne, 2007.

[3] M.S. Stachowicz, Soft Computing for Control Applications: Teacher Experience. *Proceedings of 2010 ICEE International Conference on Engineering Education*, Gliwice, Poland, July 18-22, 2010

[4] C. Carroll & M.S. Stachowicz Intelligent Control Design Using S12 Microcontroller: A Student Design Workshop, *Proceedings of 2010 ICEE International Conference on Engineering Education*, Gliwice, Poland, July 18-22, 2010

[5] M. S. Stachowicz & L. B. Kofoed , Sustainable Design and Renewable Energy in the Engineering Curriculum, *Proceedings of 2011 ICEE International Conference on Engineering Education*, Belfast, Northern Ireland, UK, August 21-26, 2011

[6] Wytec Company, "MiniDragon+ MC9S12DP256 Development Board", Wytec Co. 2002

[7] M. S. Stachowicz & L. Beall, Fuzzy Logic Package for *Mathematica*, Wolfram Research, Inc, 2003.

[8] F. Rios-Gutierrez & M. S Stachowicz,"Design Workshop on Intelligent Toys and Fuzzy Logic". *Proceedings of 2003 ASEE North Midwest Regional Conference*, Ames, Iowa, October 9-11, 2003.

[9] K.M. Passino, & S. Yurkovich , Fuzzy Control, Addson-Wesley Longman , Inc., Manlo Park, CA, 1998

[10] W. Pedrycz & F. Gomide, Fuzzy Systems Engineering, John Wiley & Sons, Inc., New Jersey, 2007

[11] T. J. Ross, Fuzzy Logic with Engineering Applications, McGraw-Hill, Inc., 1995

[12] P. J. Nahin, Behind the Laplace Transform, IEEE Spectrum, March, 1991

[13] N.S. Nise, Control Systems Engineering, John Wiley & Sons, Inc., New Jersey, 2011

[14] S.M. Tripathi, Modern Control Systems, Infinity Science Press LLC, Hingham, MA 2008,

Problem Based Learning Principles for projects with “soft” evaluation.

[1]M. S. Stachowicz, [2]L. B. Kofoed
Laboratory for Intelligent Systems, Department of Electrical and Computer Engineering, University of Minnesota, USA,
The Warsaw School of Computer Science, Warsaw, Poland mstachow@d.umn.edu[1]
Department of Architecture, Design & Media Technology,
Aalborg University, Denmark, lk@create.aau.dk[2]

Introduction

Inspired by a design workshop course offered at the Electrical and Computer Engineering Department (ECE) at the University of Minnesota Duluth (UMD) [1] we could see that the learning possibilities offered very much was using the pedagogical principles based on Problem Based Learning (PBL)[2]. In this paper we want to elaborate on these pedagogical principles to see how it could fit the requirements in future workshops for students completing their ECE program at UMD as well as workshops for Aalborg University students. When using a PBL approach students work with complex projects in small groups, so they learn specific technical topics as well as areas connected to project work (process competences or transferable skills) [3]. The combination of traditional and new engineering skills and process competences has shown to be very relevant for engineer’s future job possibilities. Studies in Denmark show that companies value those competences very high [4]. At Aalborg University a work has going on since the University start about 30 years ago to improve the PBL pedagogic approach. Development of the PBL model is a continuous process. New demands in study regulations, new generations of students and teachers need to be considered. In spite of the continuous improvements of the pedagogical approach the PBL has some ground rules which are the basic for all projects [5] but one aspect of the PBL model has not yet found a stable solution, namely how to assess and evaluate the process competences. Several assessment models have been tried out, but we still need a model which can conclude (encompass) the complex aspects of process competences also called “soft competences”.

This paper is dealing with the pedagogical principles of Aalborg University PBL model and how it can be used as a pedagogical approach for a workshop where engineering students are completing a first semester project as well as a senior design project. The Design Workshop at the ECE program, University of Minnesota, Duluth [1] is used as one case and a first year workshop at the Medialogy program, Aalborg University is the second case [6]. The focus will be at the process competencies connected to PBL in the workshops and the evaluation methods. Finally evaluation methods are discussed.

Problem Based Learning and the theoretical background for teaching and learning.

Problem Based learning (PBL) is very often an abbreviation for both Problem Based Learning and Project Organized Learning and it has proven to be a successful education strategy in several higher educations also when the pedagogical models differ from each other. In the various definitions of PBL the following three levels can be distinguished: Central theoretical learning principles; specific educational models based on PBL principles; and different practices within the guidelines of traditional educational models [2]. In Denmark where Aalborg University was founded in 1976 the university was based on the PBL approach and it is a problem – and project based model. The Aalborg PBL tradition

builds on the experiential and reflective learning more or less formulated by Kolb – the experiential learning [8], Schön – the reflective practitioner [9], and Cowan – the reflective learner [10].
The Aalborg (AAU) PBL model is based on the ideas that student's motivation and engagement is supported when students get an active role in the acquisition and creation of knowledge. Furthermore the teacher's role in the learning process has to be initiator and facilitator in a collaborative process of knowledge development and knowledge transfer. The organization of the students learning process is based on group work which means that peer-learning is becoming vital in the shared educational process of the project group [8].
The characteristics in PBL at Aalborg University, faculty of Engineering and Science are described by DeGraff and Kolmos [3] in the following:

- A problem is the starting point of the learning process. The type of problem is dependent on the specific situation of the curriculum, study regulation, semester etc. Normally a semester theme guide which problems can be dealt with. Often semester courses are planned to meet demand from the study regulation and will at the same time support the problem solving process the students have chosen for their project. It is crucial that the problem serves as the basis for the learning process because it will determines the direction of the learning process as well as a problem places emphasis on a question rather than an answer. This also allows the learning content to be related to context, which furthermore promotes students motivation and comprehension [3].
- All students work in project groups. In the first semesters the groups exist of 6 – 7 students but the number decrease during the study because a higher degree of specialization in the late semesters, so in the last semesters there will be 1 – 3 students in each project group. The students form their own groups. Each project group has 1 – 2 tutors/teachers during the whole project.
- In most cases students formulates their own problem statement within the given theme or subject area which raise the student's responsibility and motivation for their learning: participant – directed learning processes. This means that students have to find knowledge, theories and methods by themselves (supported by teachers and tutors) so they can work with and solve the problem they have chosen.
- Experience based learning is an implicit part of the participant-directed learning process, where students build from their previous experiences and interests. To actively link the formulation of the problem to the individuals or the groups world of experience increases motivation because it relates to the students previous opinions and understandings.
- Activity-based learning is also an important part of the PBL learning process. Activities involve research, decision-making and writing which also motivate and give the students the opportunity to acquire deeper learning.
- Exemplary practice is a central principle, as the students have to gain a deeper understanding of their selected problems complexity. If there is not given a sufficient broad overview of the subject area then the students need to get this understanding and thereby they have to develop the ability to transfer knowledge, theories and methods either from previously learned areas to new areas or to find new knowledge areas.
- Group-based learning is an important principle as the majority of the learning processes take place in groups or teams. Process competences will be taught as a course and the competences

will be used and developed during the project processes so the students learn to handle the process of group cooperation in all it stages.

The above principles cover the general PBL model as it is currently practiced at Aalborg University.

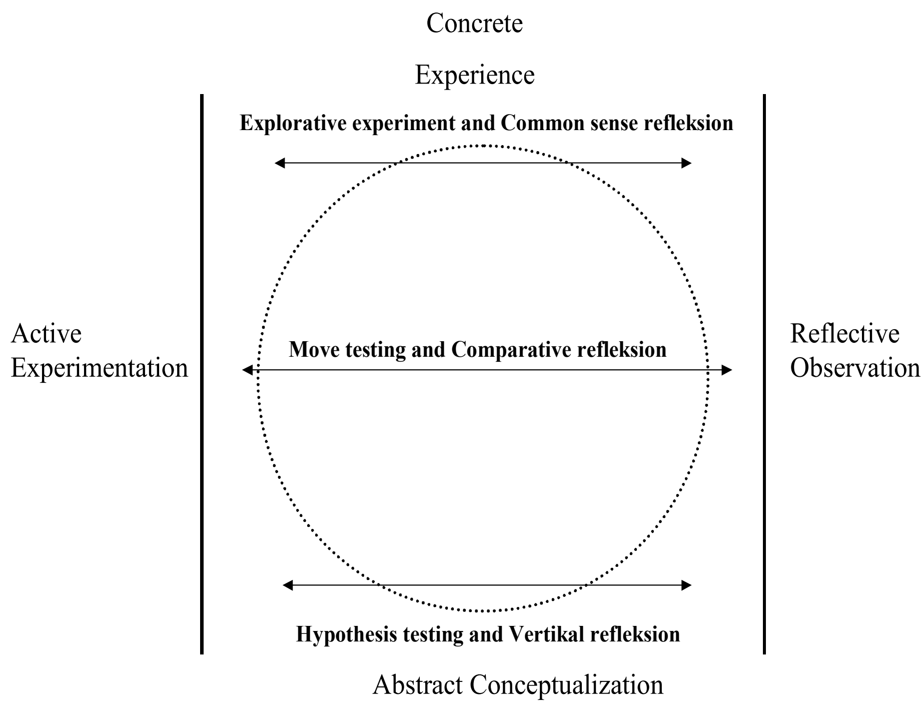


Figure1. A didactic model developed to understand the theoretical approach to teach process competences. It contains different types of reflection, which is related to a Kolb inspired learning circle. [4]

Together with the PBL principles we are using a learning model which is practical when teaching and learning the specific process competences. The model is illustrated in figure 1. The model serves two purposes. It is a description of our theoretical understanding of how students acquire knowledge in general and how to learn and teach process competencies in particular. The theoretical understanding which we are using is based on an experience-based pedagogy and is in accordance with the PBL principles.´

Process competences are very much something students are learning by doing, but they have to reflect on their experience and conceptualize their new knowledge, and they have to get a common vocabulary to communicate their experience. Teaching process competences has to be done within the group in accordance with their practical project work, and at the same time students will get a course in relevant areas of process competences. The course is called Cooperation, Learning and Project management (CLP) [3]. During the semester students are asked to carry out different experiments related to their group work and to the goals of the study regulation. As can be seen in the following, the basic approach to facilitation of experimentation and reflection is based on Schön [7] and Kolb [6]. Kolb and Schön have different understandings of how experiments and reflections can be used as learning strategies. Schön's basic concepts are "reflection-in-action" and "reflection-on-action". "Reflection-in-action" is a process where reflection and experimentation take place at the same time – in any case it is difficult to separate the two processes. "Reflection-on-action" is reflection at a distance, and it contains an element of evaluation of former actions. Kolb [6] does not deal with reflection as a method - but it is an element in a learning process consisting of experience, reflection, conceptualization and experimentation. It is important to emphasize that reflection and experimentation is separated during the learning process. It is an analytical, objective and observing reflection which involves a distance to what is going to be reflected on.

When developing the model we have used Schön and Kolb as a starting point in order to find methods, which are operational in the development of process competencies. When developing various types of reflection, research data lead us to define three different types of reflection:

1. *Common Sense Reflection* means to be conscious of the experience. This is an everyday consciousness [11]. The knowledge, which is gained from the experience, is not questioned.
2. *Comparative Reflection* is learning through comparing different experiences.
3. *Vertical Reflection* is based on induction and deduction – to be able to pass from single experiences to more abstract categories and vice versa.

Basically Kolb's learning circle should not be understood as a circle where learning only takes place if the learner reflects, forms his/her own conceptual understanding, tests hypothesis, acquires new experience as the basis of reflection etc. Studies among our own students show that they do not go the whole way round the learning circle – on the contrary, at the beginning of their study they tend to go directly from the reflective observation to new experiments without any conceptualization[3]. If the students are going to conceptualize and make more profound hypothesis testing, they must be facilitated into doing so through questions and through learning concepts, theories, models and methods connected to the field in question.

Summarizing we find that PBL is a very useful basic principle for learning process competences as students has to carry out a project in a group, they have to learn the complexity of group work when doing it. It is important to have supervisors/instructors support the student's reflections. To support the learning of process competences, we will let students make different kind of experiments connected to the process in their project group.

Case 1 - The ECE workshop, University of Minnesota Duluth

The ECE design workshop topic is the use of fuzzy logic to control comfort in solar homes [1]. In the workshop, students work in small groups of two, and are required to design, build and program a controller with intelligent behaviors using fuzzy logic. The project work actually is carried out as projects based and Problem Based Learning (PBL) principles [2]. This pedagogical approach implies that the students within a theme choose which problem they want to investigate and solve in their projects. There might be some demands and restrictions connected to their learning goals, but apart from this it is up to the students to analyze the problem area, define the specific problem they want to solve, choose methods, implement, test and evaluate results. In the workshop no formal lectures are taught; however the students receive an intensive review covering the topics of the 68HC12 microcontroller, sensors and fuzzy logic control. Usually a team of two faculty members is connected to the workshop, and the main role of these instructors is to guide and advise students in order to develop a real engineering project. One of the challenges for the students is to understand the concept of comfort in connection with in-door climate. Another challenge is to organize the group and the project. Since no formal lectures are taught in this workshop, an intensive review, covering important material related to the specific topic, is given at the beginning of the semester. In particular for the robotics, and intelligent systems topics, the reviewed material includes: the MC68HC12 architecture and assembly language, introduction to robotics, sensors for robotic applications, motors and drivers, and fuzzy logic. Several papers and references are given, and students are encouraged to read the material, analyze the complicated problem area, and define the final problem statement they want to solve which means that students are exercising their self-leaning skills. Furthermore students have to consider their own detailed project plan according to the overall plan for the workshop. It is important to have in mind that since this is a capstone design, students should be able to apply the knowledge and skills that they have learned in previous courses to solve problems that will emerge during the development of the project. This means that the students have to show ability to use, combine and generalize previous gained knowledge in a new situation as shown in fig 1. Furthermore students have to organize how to work and contribute to their project and set up detailed work plans.

The students obtain specific technical knowledge according to the study program. But they also get knowledge about group work and managing a project as well as presenting a poster and a project that gives valuable competences within planning and communication skills [4].

The workshop ECE 4951-Spring 2010 had fourteen students and two advisors and the workshop ECE 4951-Fall 2010 had four students and two advisors.

In the workshop, teams of two students are formed. Each team is encouraged to develop ideas of their own and present a proposal for their project. All the proposed projects should fit into the selected topic, and should be reviewed and approved by the instructors. The students have fifteen weeks to do all the work, from the definition to the development and completion of the project. During the semester, students and instructors meet once a week. Students discuss about their progress, and problems that they are having in the projects and the instructors give suggestions.

Evaluation of the projects

Upon completion of this course the student should be able to:

- Complete a design project that is interdisciplinary in nature, integrating the knowledge obtained in previous ECE classes
- Accurate communicate his/her project results, both in written report format and in oral presentation format
- Understand how teams work and how to interact in a team setting. (Understand what it is like to work in industry)
- Appreciate the role of engineering in society, and ethical issues

The projects are evaluated in several stages, in a gradual and continuous way. In the weekly meetings each team presents the evolution of their projects and receives orientation of the instructors. The objectives of these weekly meetings are also to have a close observation of the teams' progress and assure that each team member contributes to the teamwork. For the final grade, all the members of each team obtained the same grade. 35% of the final grade is assigned during week nine, when students present a written report and oral presentation of the results of their simulations. Another 35% of the final grade is assigned to the students during week fifteen when they demonstrate that their project is working in accordance to the specifications. The last 30% of the final grade is assigned based on the final oral presentation, taking into account the quality and clarity of the presentation, and the completeness of the final written report and quality of the poster.

The process competences are close connected to the project work in general, and it is in a way expected that the students perform according to what it takes to carry out a project and work in a group. The students get feed-back during the project process about the project progression, and the relatively small numbers of students and teachers make it possible for the teachers to get a profound knowledge about the process of all groups standpoint regarding the technical as well as the process competences. The question is how much the students are aware of those specific and highly valued process competences in the way projects are carried out in this case.

The evaluation of the project is usually described in natural language terms, since a numerical evaluation is often too complex, too unacceptable. For example, when grading a written final report we evaluate it from several perspectives as creativity, style, grammar, and so forth. The final grade on the paper is linguistic instead of numeric, e.g. excellent, very, good, good, fair, poor, and unsatisfactory. The process of determining a grade for a specific report is equivalent to the process of determining a membership value for the report in each of the evaluation categories and this process is implemented through the composition operation. [11]We apply similar algorithm for evaluation of the hardware demonstration and poster quality. Professor Timothy J. Ross [12] introduced the name for this process "the fuzzy synthetic evaluation".

Case 2. Intro workshop for 1. Semester, Medialogy

Each semester has goals described in the study program, and the goals has to be reflected in all projects. Furthermore each semester has a theme within which students can chose which problem they want to work with.
The first semester is meant as an introduction to the Aalborg University study form. The students will be introduced to the group and project work in a small introduction project of 3 weeks. The character of the introduction project serves as a general workshop, which includes several minor workshops and courses. The reason is that the students have to get some experiences by doing a complicated project in a group when at the same time they have to participate in different course activities which have their own deadlines for connected assignments. This is a real challenge regarding planning. They are also encouraged to start small experiments about topics related to the group and project process like working according a time and activity plan which they have to use as experiment. Data from the experiments can be used in the process analyses. During the whole process students are told to reflect about the different elements in the project work.

The semester theme is ‘Visualize the unknown’. In the following semesters projects students have to choose which problem they want to work with in their project, but in this introduction project the choices are limited to 3 elements: a 2 - 3 minutes presentation of a fellow group using Flash and Photoshop as well as a documentation of the production, a PBL essay and a Poster about Medialogy (max 20 pages + cd). Within each element the students can chose how they will accomplish each task. In the project group they have to discuss the task, find a solution, plan and organize the work in the group and solve the different problems connected to the project and the group work. During this 3 week students have 1) a Flash and Photo workshop with courses, 2) an animation and graphic design workshop and 3) the start of a course in CLP (Cooperation, Learning and Project Management).

The first semester has 160 students and they are placed in 22 project groups with 6 – 7 students in each group. A team of 8 teachers/supervisors are connected to the first year. Each project group has a supervisor connected during the process. The supervisors have meetings once a week with the groups, but groups can get further assistance if needed.

After finishing and submitting the introduction project each group has to write a process analysis, which is a 3 - 4 pages reflection about the process in the project group (the planning, the cooperation, the project management etc). The process analyses have to be submitted within 36 hours.

Evaluation of the introduction project

The goal of the introduction project the students have to demonstrate:

- use different methods to collect and analyze different data,

- to communicate their findings in academic ways for different target groups.

- the three elements plus the process analysis have to use definitions and methods used in the courses and workshops.

The groups are not evaluated during the process. For evaluation the groups will present the projects and the process analyses. The group has to choose how to present the project, but the precondition is that all members of the group have to present a part of the project within 30 min. Then there is an individual oral exam based on the topics in the project.

The process competences are very close connected to the projects, but when students start the project, they also start their CLP course and they have to write a PBL essay, so they begin to have an understanding of the process competences as well as they get definitions and a common vocabulary. The process analysis are written documentation about each groups level of comprehension and understanding of the project process, but still with so many students, groups and teachers it is very difficult to evaluate each group and individual in a fair and constructive way.. The challenge is to formulate clear criteria for design an evaluation which can be used for more than 100 students and a big team of teachers.

Conclusion and discussion

The two cases show that different ways of establishing and carry out a student’s project based on PBL principles has much potential for the students to achieve process competences. The way to teach process competences can be different depending on which semester the students attend, and how important the process competences are in the curriculum and the study regulations. The “soft evaluation” is dealing with so-called “soft competences”, but if the students and their future employers really have to benefit from this subject we have to more clear about defining and evaluating these competences in ways which are as reliable as the evaluation methods used for technical competences. A way could be a combination of a formative evaluation made during the process, but with clear topics to be dealt with regarding the progress of the project and the group, and a summative evaluation once or twice during the project. The challenge will be to design and implement the final evaluation which will give the students an understandable impression about his/hers competences in a way to be used in their CV.

A future research project about assessment of “soft competences” is planned, and the aim is to design and implement different methods for assessment using a combination of formative and summative assessment models with an addition of elements from fuzzy logic.

References

[1] Stachowicz, M. S. and Kofoed, L. B (2011): Sustainable Design and Renewable Energy in the Engineering Curriculum. In proceedings from The International Conference on Engineering Education. Belfast.

[2] Kofoed, L.B. & Hansen, S. (2004), Teaching process competences in a PBL curriculum. In: *Kolmos, A. et all (eds.)The Aalborg Model: Progress, Diversity and Challenges.* Aalborg University Press.

[3] De Graff, E. and Kolmos, A. (2003): Characteristics of Problem-Based Learning. International Journal of Engineering Education.

[4] Kofoed, L.B. & F. Jørgensen. (2007), Using Problem Based Learning Methods from Engineering Education in Company Based Development. *Proceedings of the 18th Conference of the Australasian Association for Engineering Education*. Melbourne : Department of Computer Science and Software Engineering, The University of Melbourne.

[5] The Danishh Journal, Ingeniøren, 2008

[6] Barge, Scott (1010) Principles of Problem and project Based Learning, The Aalborg PBL Model. Aalborg University. www. AAU.dk

[7] Pedersen, J.R. and Kofoed, L.B. (2011) Challenges of changing a PBL-related curriculum for 1th year students. In proceedings from The International Conference on Engineering Education. Belfast.

[8] Kolb, D. A. (1984) Experiential Learning. Engelwood Cliffs, NJ: Prentice-Hall.

[9] Schön, D.A.(1987) Educating the Reflective Practitioner. San Fransisco: Jossey-Bass.

[10] Cowan, John: (2006) On Becoming an Innovative University Teacher, reflection in action. Society for Research into Higher Education & Open University Press. Second edition.

[11]Strachowicz, M.S. and Beal, L. (2003) Fuzzy logic Package for Mathematica, Wolfram Research Inc.

[12] Ross, T.J. (1995) Fuzzy Logic with Engineering Applications, McGraw-Hill Inc.

Biographical Information

Dr. Lise Busk Kofoed is Professor and head of the Medialogy section, Aalborg University, Copenhagen, Denmark. Her research areas are within development of the Problem Based Learning (PBL) concept within engineering educations with special focus on cross disciplinary programs, development of transferable skills in PBL and project work, methods to change management and staff development.Dr. Kofoed is a board member in UNESCO International Centre for Engineering Education for Problem Based Learning, Aalborg University.Dr. Kofoed has more than 100 publications in books, journal papers and conference proceedings, and has been responsible for several national and international research and developmental projects. Dr.Kofoed holds a Ph.D. in “Working Environment and Learning”.

Professor and Jack Rowe Chair Marian S. Stachowicz heads the Laboratory for Intelligent Systems at the Electrical and Computer Engineering Department, University of Minnesota Duluth, USA. Currently he is also Visiting Professor at the Warsaw School of Computer Science, Warsaw, Poland. He received his M.S. degree in Control and Computer Engineering from LETI, Soviet Union and both his Ph.D. and D.Sc. from AGH - University of Science and Technology, Krakow, Poland. Professor Stachowicz has published 7 books, 130 papers in journals, conference proceedings, and 20 patents. His work centers on artificial intelligence and soft computing, decision analysis and control. Prof. Stachowicz received two prestigious awards for introduction digital fuzzy sets and he is co-author of the Fuzzy Logic Package for *Mathematica*.

A nanotechnology module within the current course in Engineering Economy

Mitchell Cornelius[1], Bidhan Roy[2], Osama Jadaan[2]
[1] Department of Mechanical Engineering, [2] Department of General Engineering
University of Wisconsin – Platteville, 1 University Plaza, Platteville, Wisconsin 53818, USA

Abstract: For the past couple of years, the college of engineering has been offering a minor program in microsystems and nanotechnology. This has recently been upgraded to a major. Concurrently, efforts are underway to introduce this new field in existing courses, so as to entice student's interest. This study deals with creating a nanotechnology module in our course in Engineering Economy. A typical course work in engineering economy includes employing valuation tools and benefit-cost analysis (among many others) to study the financial feasibility of engineering projects. Unfortunately, for projects involving nanotechnology, the finances are mainly speculative since commercial applications of nanotechnology are mainly at its infancy. Hence, we targeted small and medium enterprises (SME's) dealing with nanotechnology related products and listed at NASDAQ. This is because such companies would have their financial statements freely available in the internet. The module consists of designing sample valuation problems of the SME's created from their income statement. When first offered in Fall 2011, it is expected that it shall help students understand a financial statement, the future sway of nanotechnology related products in markets, and the volatility (risk) faced by the start-up companies.

Introduction

Nanotechnology is the study of manipulating matter at the nanoscale (10^{-9} m). This would involve studying material behavior at the atomic and molecular level. Therefore, it encompasses diverse areas such as surface science, organic chemistry, molecular biology, semiconductor physics, microfabrication etc.

Nanotechnology has the potential to create many new materials and devices with a vast range of applications such as medicine, electronics, biomaterials, and energy production. Therefore, it becomes imperative to introduce and train our new generation of engineers to this exciting field. In this regard, the College of Engineering at University of Wisconsin – Platteville has recently upgraded its minor program in micosystems and nanotechnology to a major program.

In order to draw students towards this new major program, a nanotechnology module as been incorporated into the coursework of Engineering Economics. This is because this is a course taken college wide and fulfills the objective of a wider audience. Besides, it also introduces the students towards the initial commercialization of this new technology and the volatility of the related startup enterprises.

This paper describes the initial steps taken to develop the module. We begin with a section describing the contents of a typical engineering economics course. This is followed by a section describing the steps taken to develop a module. An essential part of the module will be in comprehending financial statements and constructing sample valuation problems and the subsequent sections describes them.

Engineering Economy 101

Engineering economy is the study of viability of engineering projects from a financial point-of-view. The decision on viability of the projects primarily stems from three type of analysis[1] –

1. Valuation analysis: Based on the financial data, we calculate the present worth (or annualized worth or future worth) at prevailing interest rate. If we are dealing with a single project, we choose the project if the valuation is positive. Otherwise, we shall choose the "do nothing" option. If we are dealing with a multitude of projects, we choose the project with the highest valuation.

2. The internal rate of return (IRR) analysis: The internal rate of return is the interest rate at which the cash flow of the project breaks even, ie., the interest rate at which valuation is zero. If we are dealing with a single project, we execute the project if the IRR exceeds the market interest rate. Else, we "do nothing". Again, if we are dealing with a multitude of projects, we choose the project with highest IRR (assuming all IRR's exceed the market rate).

3. Benefit-Cost analysis: If we know the dollar value of the benefits associated with a project, we compute the ratio, benefit/cost (or the difference, benefit-cost). If the ratio is greater than one (or if the difference is positive), the project is executed.

Engineering Economy of Nanotechnology Related Companies (or Projects)

It is very difficult to undertake an engineering economic analysis for a nanotechnology related company (or project). This is because commercial applications of nanotechnology are still in its infancy and therefore many financial data is merely speculative. Besides big corporations undertaking nanotechnology related projects (such as General Electric, IBM, and Intel etc.) do not state the finances specific to the project.

In order to circumvent the lack of financial data, we focused our attention on NASDAQ listed small and medium enterprises (SME's). The rational for doing this is – (i) such companies are solely devoted to developing and marketing nanotechnology related products; and (ii) since they are listed in NASDAQ, they have financial statements – income statements, cash flow statements, and balance sheet statements, in the public domain in the internet.

Most of the financial statements – income statements, cash flow statements, and balance sheet statements have a myriad of financial data. Some of these data describe the operational income and expenses, whilst others are related to accounting practices. The financial data for an engineering economic analysis are mainly associated with operating income and expenses. Therefore, we use an income statement for our analysis.

In the subsequent section we shall briefly describe an income statement and the financial data we are concerned with. This will be followed by a section describing the model problems we devised for an engineering economy analysis. Finally, we conclude by describing the future direction of this study.

Understanding an Income Statement

The purpose of an income statement is to provide investors the most accurate description of the company's profitability over a set period of time, usually a fiscal quarter (3 months) or a fiscal year (12 months). This includes an estimate of the firm's sale, costs, increase or loss in intangible value, taxes, outstanding shares, and how the resulting net profit is divided among shareholders.

But as stated earlier, we would be dealing with operational costs. Among them are[2] –

(a) Total Revenues: This is the amount of money earned by selling the product.

(b) Cost of Sales (or cost of revenues): These are direct costs of production. They may include manufacturing employee salaries, cost of raw materials, cost of electricity and other utilities to run the factory, packaging material, and so forth.

(c) Research & Development: In order to consistently produce faster and better products, the company has to spend a lot of money on development labs, engineering resources, prototyping products etc. These expenses are recorded here.

(d) Marketing (or selling), General, and Administrative: These include advertising expense, executive salaries, stock options, and any other costs that cannot be grouped elsewhere.

(e) Income Tax Expense: Here the accountants calculate what they believe the tax rate would be and set aside a portion of profits (revenues) to pay taxes.

Designing an engineering economy module for nanotechnology companies (or projects)

Since engineering economy is best understood by solving problems, the students can have a better understanding of the importance of nanotechnology in a future economy by devising problems, and applying the procedures of economic analysis (described earlier) to study them. This will help students make educated inferences about how nanotechnology products will help drive future markets. Sample problems related to three NASDAQ listed SME's are described below –

Problem 1:

NVE CORPORATION

Nonvolatile Electronics, Inc. (NVE Corporation, NASDAQ: NVEC) is based in Edina Prairie, MN. Founded in 1989, the company is a market leader in nanotechnology sensors, couplers, and MRAM intellectual property (Magnetoresistive Random

Access Memory).

NVE's technology enables the transmission, acquisition, and storage of data across a broad array of applications, including implantable medical devices, mission critical defense weapons, and industrial robots.

The financial health of the company (all number in 1000's) as described in its income statement is as follows[3] –

Year	3/2008	3/2009	3/2010	3/2011
Total Revenue	$20,528	$23,372	$28,147	$31,197
Cost of Sales	$6272	$6250	$7923	$9372
Research & Development	$1487	$1218	$1121	$1269
Selling, General, & Administrative Expenses	$2158	$2177	$2414	$2474
Income Taxes	$3892	$4644	$5917	$6330

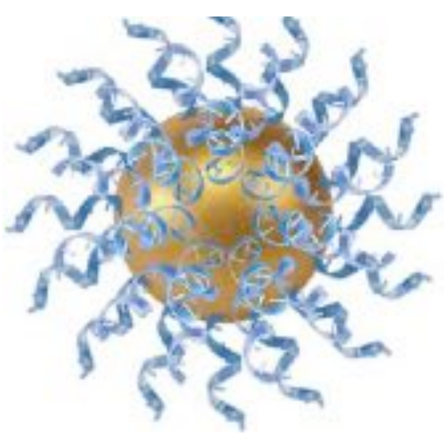
(a) Based on the above data, calculate the present worth of the company. Use an interest rate of 4% per annum.

(b) Based on the present worth, would you like to invest in the projects of this company?

(c) Calculate the IRR and based on the IRR analysis, would you like to invest in the projects of this company.

WARNING: In real life, any decision on whether to invest or not, will depend on more factors than those presented above.

<u>Problem 2</u>:



Nanosphere, Inc. (NASDAQ: NSPH) is a nanotechnology based healthcare company, offering a range of proprietary breakthrough technologies that provide a unique and powerful solution to greatly simplify diagnostic testing.

Founded in 2000, based upon nanotechnology discoveries at Northwestern University in Illinois by Dr. Robert Letsinger and Dr. Chad Mirkin, the company is involved in consistent manufacturing and functionalization of gold particles with oligonucleotides (DNA or RNA), or antibodies that can be used in diagnostic applications to detect nucleic acid or protein targets, respectively.

The financial health of the company (all number in 1000's) as described in its income statement is as follows[4] –

Year	12/2007	12/2008	12/2009	12/2010
Total Revenue	$1167	$1366	$2214	$2026
Cost of Sales	$2487	$2468	$1391	$865
Research & Development	$21,364	$23,675	$18,607	$18,821
Selling, General, & Administrative Expenses	$13,443	$13,615	$14,471	$22,007
Income Taxes	$1,977	$2080	$1257	$274

(a) Based on the above data, calculate the present worth of the company. Use an interest rate of 4% per annum.

(b) Based on the present worth, would you like to invest in the projects of this start-up company?

(c) Calculate the IRR and based on the IRR analysis, would you like to invest in the projects of this company.

WARNING: In real life, any decision on whether to invest or not, will depend on more factors than those presented above.

<u>Problem 3</u>:
Veeco Instruments Inc. (NASDAQ: VECO) based in Plainview, NY, is a leading supplier of process equipments for nanotechnology labs in industry, university, and government laboratories. Some of the equipments deal with metal organic chemical vapor deposition (MOCVD) for LED's and solar cells, and molecular beam epitaxy (MBE) products.

The financial health of the company (all number in 1000's) as described in its income statement is as follows[5] –

Year	12/2007	12/2008	12/2009	12/2010
Total Revenue	$402,475	$442,809	$380,149	$933,231
Cost of Sales	$203,223	$251,871	$211,463	$478,370
Research & Development	$61,174	$60,353	$57,430	$71,390
Selling, General, & Administrative	$90,972	$92,838	$85,455	$91,777

Expenses				
Income Taxes	$3651	$1892	$1347	$10,472

(a) Based on the above data, calculate the present worth of the company. Use an interest rate of 4% per annum.

(b) Based on the present worth, would you like to invest in the projects of this company?

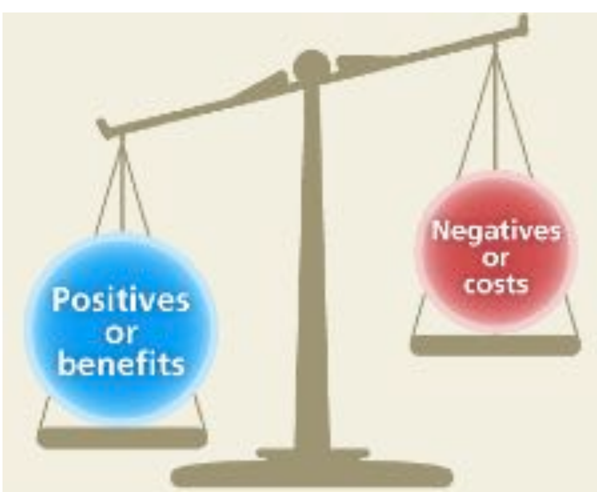
(c) Calculate the IRR and based on the IRR analysis, would you like to invest in the projects of this company.

WARNING: In real life, any decision on whether to invest or not, will depend on more factors than those presented above.

Discussion and Future Directions

This engineering economy module for nanotechnology has been designed in order to introduce this new innovative field to undergraduate students from an economic standpoint of view. Since commercial applications of nanotechnology are still in its infancy, data from financial literature is speculative at its best. Therefore, we focused solely on nanotechnology based small and medium enterprises (SME's) listed at NASDAQ. This was because their business is exclusively based on nanotechnology and their financial statements (and specifically income statements) is readily available in the internet.

There will be many advantages when such a module is administered within the existing course in engineering economy. To begin, students will learn to comprehend the data in an income statement, unlike a typical textbook problem where the cash inflows and outflows are already mentioned within a problem statement. Besides, the problems will help understand how nanotechnology related products can have a sway on the markets in future. Also, the students will learn about the vulnerability (or volatility) of start-up companies.



A complete economic study should include benefit-cost analysis. But to undertake such an analysis, one should have data on the dollar-value of the benefits of nanotechnology related products.

For example, consider the company NVE Corporation. Their MRAM (magneto-resistive random access memory) intellectual property will play a big role is saving data in a computer when there is abrupt disruption of power supply. This is the benefit of their product. But in economic terms, the benefit would be the "dollar value" of the money saved due to prevention of data losses in a computer whenever there is abrupt disruption of power supply.

Since the commercial applications of nanotechnology are still in its infancy, we need to do more detailed analysis of financial literature to collect such data on benefits. This shall be the goal of future studies in this topic.

Bibliography

1. WHITE, J.A., CASE, K.E., and PRATT, D.B., "Principles of Engineering Economic Analysis", 5'th edition, John Wiley & Sons, Inc., 2010.
2. http://www.magicdiligence.com/articles/understanding-the-income-statement, 2009.
3. http://finapps.forbes.com/finapps/jsp/finance/compinfo/IncomeStatement.jsp?tkr=nvec&period=qtr
4. http://finapps.forbes.com/finapps/jsp/finance/compinfo/IncomeStatement.jsp?tkr=NSPH
5. http://finapps.forbes.com/finapps/jsp/finance/compinfo/IncomeStatement.jsp?tkr=VECO

Biographical Information

MITCHELL CORNELIUS (Decorah, Iowa) is a senior in Mechanical Engineering with a minor in Microsystems & Nanotechnology. On graduation, he intends to pursue research studies in nanobiosciences.

BIDHAN ROY (PhD 2003, UIUC) is an assistant professor with the Department of General Engineering, University of Wisconsin – Platteville. His research interests are primarily in mechanics with a focus on biological systems, applied mathematics, and numerical methods.

OSAMA JADAAN (PhD 1990, Penn State) is a professor with the Department of General Engineering, University of Wisconsin – Platteville. Dr. Jadaan's research focuses on probabilistic design and structural reliability evaluation of structures, including silicon and SiC MEMS devices. His research with NASA has led to creation of CARES/Life, an industry standard integrated design software. Currently he collaborates with government labs such as the DOE, ARL, and NVL and consults numerous energy companies.

Emphasizing Environmental Health and Safety Training in all Aspects of the Emerging Nanotechnology Field

Seraphin C. Abou
Mechanical and Industrial Engineering Department, Environmental Health and Safety Program, University of Minnesota Duluth, 1305 Ordean Court, Duluth, MN 55812, USA; Email*: sabou@d.umn.edu*

Abstract:
Progress in engineering and the life sciences, including nanotechnology and high-throughput experimentation, offers an opportunity for understanding material science, biology and medicine from a systems perspective. In this paper, we propose new safety system teaching approaches in the emerging nanotechnology field of study. They focused on the departure from the traditional instructional models without fully discarding them. The educational objectives are to expose students to the open-endedness nature of professional engineering discourses, to appreciate the interconnectedness of knowledge disciplines and the multidisciplinary nature of professional engineering practices, and to instill into students with skills and knowledge which are convergent with the higher levels of Bloom's taxonomy. This "*new view"*, which complements the more traditional component-based approach, involves the integration of biological research with approaches from engineering disciplines and computer science. The method results in more than a new set of risk assessment technologies. Rather, it promises a fundamental reconceptualization of the environmental health and safety training based on the development of quantitative and predictive models to describe crucial processes. To achieve this change in safety culture, learning communities (International Curriculum on Nanotechnology) are being formed at the interface of biology systems, engineering and computer science. Through this new teaching/learning communities, research and education can be integrated across disciplines and the challenges associated with multidisciplinary team-based science and engineering can be addressed. The results show a general positive relationship between the use the learning technology and student engagement and learning outcomes.

Keywords: Engineering education, Nanotechnology, System safety, Multidisciplinary teaching

1. Introduction

From macroscopic perspectives, the emerging field of nanotechnology represents an integration of concepts and ideas from the life sciences, systems biology, engineering disciplines and computer science. Recent advances in nanotechnology, including biotechnology and massively parallel approaches to probing biological samples, have created new opportunities for understanding engineering and biological problems from a systems perspective. Systems safety becomes a key component that supports the development of this new technology. For this new technology in embryonic development, system safety led the perspective to regard the potential of collaborative learning and cooperative learning as strong instructional strategies. Hattie's (2009), [4], more recent meta-analyses point to a number of critical conditions that are needed to attain a positive impact of collaboration. Johnson and Johnson (1996), [6], cite certain guidelines that must be met to support collaboration: guarantee individual accountability, assure group accountability, develop communication skills, make sure that shared objectives are pursued, and break down complex group tasks.

Nanotechnology-based products have emerged as the most commercially viable products of this century because of their wide-ranging utility in our daily lives. These products have the potential to affect the health and safety of the industrial workforce and the general public. Nanostructured materials such as nanotubes, fullerenes, nanopowders, dendrimers, nanoparticles, nanocrystals, and nanocomposites are globally produced in large quantities due to their wide potential applications (e.g., in skincare and consumer products, photonics, healthcare, biotechnology, pharmaceuticals, and drug delivery), [10], [12], [13]. However, the environmental, health, and safety uncertainties posed by these products need to be characterized, due to the fragmentary scientific knowledge of their health and safety risks. With classical engineering training and design, often, systems are designed and then an attempt is made to add safety features or to prove that the design is safe after the fact, or to detect accident causes after catastrophic events.

The proposed approach in system safety training emphasizes the functional behavior of collections of components working together and builds upon the more traditional approach of studying the individual roles of single components. Systems modeling and design are well-established in engineering disciplines but, until recently, have been relatively rare in biology. To explore the application of complex systems analysis to nanotechnology and public safety concerns, multidisciplinary teams of biologists, engineers and computer scientists are working together – applying principles and techniques from engineering with concepts and algorithms from computer science to solve problems in nanotechnology safety and medicine.

Building on the international curriculum on nanotechnology to support communication, collaborative learning has also become an integral part of learning management systems. From systems safety perspective, the integration of the international curriculum has brought about a new strand of educational research focusing on public safety, computer conferencing, biology systems, computer-mediated communication, also resulting in an established research field known as computer supported collaborative learning, a new area in engineering learning and teaching. In addition, Henri (1992), [5], introduced quantitative approaches (such as the number of messages, level of interaction) and qualitative approaches (such as surface or deep level processing) to study the impact of collaboration in these online learning environments, Pena-Shaff and Nicholls, (2004), [11].

To be truly effective, safety culture and community learning structures must be built to facilitate the interaction of researchers, educators and students from multiple disciplines. This effort is aimed at integrating multiple interests into one community, a community of safety practice. In addition, educational programs must be recast to produce a new breed of researcher prepared and suited to working at the interface of multiple disciplines, thereby creating a second type of integration, a new learning community. However, several barriers must be overcome to achieve both forms of integration effectively. Progress has been made in developing international curriculum and building research communities at universities to approach problems in health and safety, systems biology, and frequently these communities are built around graduate students and their education. I this paper, we discuss challenges to and strategies for integrating students, staff and faculty from multiple disciplines to create new learning communities at the interface of biology, engineering and computer science.

2. A new approach to nanotechnology safety training

To be free of peril is a universal goal that has been common to all eras and all peoples. The desire to be safe and secure has always been an intimate part of human nature. Humanity becomes technical in the means to provide the objects and conditions necessary for sustenance and physical contentment.

Through the years, the content and method of "*safety training*" programs and organizational safety related problems have changed in two important ways. First, there is an increasing emphasis on total process safety as compared with the traditional focus on "*individual accidents.*" This is most obvious in the various aspects of organization liability and in areas relating to environmental impairment, and new technological risks. Second, there is an increasing need for formal cost-benefit justification for safety related activities, including training. In response to these needs, there is an increasing tendency of general management to think in terms of more formal safety related organizational training and global safety training programs to prepare personnel to deal with multidisciplinary nature of "*modern risk"* management. Unfortunately, existing safety training programs along with the safety professionals who conduct them, are often not prepared to deal with this global organization approach to safety. Systematic safety training reflects the major theme of this paper. Our desire is to maintain a position of organizational credibility and to implement safety training programs in the modern management environment. Therefore, in the proposed method, an implicit emphasis is placed on the need for formality and rigor in designing and conducting training and behavioral modification programs (i.e., safety culture) in today's modern legal and economic climate. More importantly, it is because the need for congruence between safety concerns (e.g., safety driven-design, new technology risks, etc…) and the demands of management is becoming increasingly evident.

Based on Bloom's taxonomy we understand that learning can start at any point, but inherent in that learning is going to be the prior elements and stages. In this sense, the use of systems concept for safety training provided new insights in the assessment of safety-critical systems. These new insights have led to systematic approaches to solving many safety problems and producing significant improvements. These improvements result from thinking about old safety problems (e.g., sloppy design, unreliable performance) in new ways: problem based learning framework, safety-driven design etc...).

In the past decade, Bloom's (1956, 1984), [2], taxonomy of educational objectives was developed as a tool for a variety of purposes. His taxonomy is organized from simple to complex, and concrete to abstract cognitive categories, representing a cumulative framework that has been widely applied in educational research, [7], [8]. More specifically, Bloom's categories reflect levels in knowledge construction. In this study, we have adopted Bloom's taxonomy as a "*style*" about learning goals to facilitate communication across persons, subject matter, and grade levels. Constructing knowledge implies movement from basic descriptive comments of opinion to using a variety of cognitive strategies, such as analysis, evaluation and creativity, [1]. However, there are conceptual and application limitations in using any taxonomy. For instance, Kunen et al. (1981) questioned whether evaluation should remain as the highest level of the original taxonomy. Former students of Bloom have revised the original taxonomy, [1]. Their changes especially affected the structure of the taxonomy. Instead of a unidimensional structure, they present a two-dimensional table. The knowledge dimension refers to the type of knowledge being learned (factual, conceptual, procedural, or meta-cognitive).

In the original concepts of Bloom's taxonomy, the cognitive process dimension refers to six levels in cognitive processing. These concepts are now reviewed and presented as active verbs, and two categories were changed as to their hierarchical position: evaluation and creating. In the context of the present study, we examine the latter possibility. Then, from systematic safety training aspects, and without lost of generality in safety engineering context where safety and reliability are the keys, we reformulated Bloom's cognitive process dimension as to be applicable to analyze system safety learning outcomes, safety culture, and the cognitive process used by students to design a system with lowest risks as low as reasonably practicable. Safety system training version of these concepts is illustrated in figure 1.

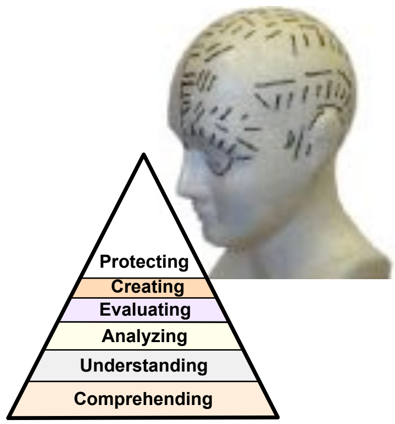


Fig.1 Modified Bloom's taxonomy for safety training objectives

Note that there isn't a magic bullet for engaging students. We developed this approach to assess the extent to which they engage in educational practices associated with high levels of learning and development of safety culture. We adopted Bloom's taxonomy to direct the analysis of international curriculum development contributions to system safety culture improvement. In the present study the taxonomy categories are not only adopted to analyze the cognitive processing level that this kind of development may provide. The present study also adopts the taxonomy as a scripting guide for the students. Students from diverse disciplines enrolled in environmental health and safety program were asked to add to each of their response to the survey questions a label that is based on one of the cognitive process categories in Bloom's taxonomy. Questions we asked were for example: what motivates and inspires the students who are attracted to the program, what types of careers do they plan to follow, and what specific issues are important to them?

This modified taxonomy attempts to account for the new behaviors and actions emerging as technology advances and becomes more ubiquitous. The design of this curriculum describes many classroom practices and learning objectives including the new processes and actions associated with communication technologies, the exponential growth in information, and increasing ubiquitous personal technologies or cloud computing.

3. The role of theory in nanotechnology safety training

Commercialization of nanotechnology will provide economic expansion and jobs but it also may have the potential to directly impact the workforce at large from two perspectives. First, to date a complete understanding of the health effects of workplace exposure to nanoparticles/nanomaterials is not available; consequently, safety and health engineering technologies and best practices are not currently in place to protect the workforce well-being along the lifecycle of nano-based products including workers in nanomanufacturing enterprises and the environment, and public health. Second, nanotechnology may potentially be used for the prevention, early detection, and treatment of occupational diseases (e.g., musculoskeletal disorders, pulmonary diseases), whose healthcare costs are burdening the US and global economies with billions of dollars.

Theory is needed to deepen the understanding of this new technology and the associated risks. The main purpose of the new curriculum is to present an education and research framework for the emerging interdisciplinary field of nanotechnology occupational and environmental health and safety to advance the field with respect to (1) the protection and promotion of worker safety and health in nanomanufacturing enterprises/environment and consumer public health, and (2) the prevention and treatment of occupational diseases through the use of nanotechnology.

Nanoparticles can have the same dimensions as some biological molecules and can interact with these. In humans and in other living organisms, they may move inside the body, reach the blood and organs such as the liver or the heart, and may also cross cell membranes.Without significant efforts to establish technologies and best practices in laboratories and work environments, the quality of life of the workforce may be affected because of potential adverse health effects of these new materials. Further, the dispersion of nanoparticles into the general environment and the impact of exposure to the general population need to be considered in a proactive manner.

The expected outcomes of the proposed education and research framework include, among others, (1) a roadmap and a guide for individual health and safety promotion and protection along the life cycle of nano-based products (i.e., nanomanufacturing enterprises, environment, product use, and disposal activities); (2) establishment of focus groups for advancement of integrated solutions and issues of immediate concern to individual health and safety in different nanomanufacturing sectors/environment/disposal activities, and health of public consumers of nano-based products.

Supplemental options that could be considered along with the proposed training program include guidance in how to establish the proper mix of slow and rapid change that includes strategic realignment with the past combined with an adaptive orientation towards the future. Of course opportunities to develop key competencies consistent with the challenges of advanced manufacturing, information technology, emerging materials, and other factors is necessary.

4. A framework for the education and research program

A variety of mechanisms at universities worldwide are addressing the dual challenges of conducting multidisciplinary, and often team-based, research projects in systems biology while also educating a new breed of researcher to assume leadership positions in this emerging field. Notably, California has the opportunity to create a 21st Century multi-ethnic workforce to meet the evolving and complex challenges of converging technologies—particularly nanotechnology, Micro-Electro-Mechanical Systems or "MEMS," and advanced manufacturing technology—that will dramatically change the state's manufacturing sector by 2015.

The proposed education and research program is centered on the impact of nanotechnology on occupational and environmental health and safety from two perspectives, (Figure 2). The life cycle of nano-based products envisioned is depicted in Figure 2. The education program will deal with integrated solutions and current issues of immediate concern to personnel who are currently or will be exposed to nanoparticles, nanomaterials, or nano-products and consumers of nano-based products. The research program will be centered on developing research agendas and dissemination of the latest research findings as outlined in Figure 2.

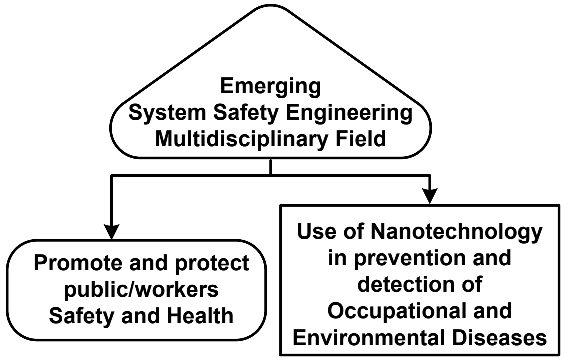


Fig.2 Broader objectives of nanotechnology occupational and environmental safety

At the University of Minnesota Duluth (UMD), we are finding that many students are well-suited to and interested in joint mentorship of their research by two faculty members with different backgrounds. By integrating fully into two research groups and learning how each one thinks and approaches problems, these students will be uniquely qualified to tackle non-traditional interdisciplinary research questions on their own. In addition, they will be well positioned to act as integrating agents in the community by serving as communications bridges or translators between two distinct research groups and approaches. Together, the emerging student profiles are beginning to define niches in the educational, cultural and research landscape of modern systems biology; the coming years will further refine the relationships among students, skills, classroom subjects and research areas that will further affect how learning communities in systems biology organize themselves.

The healthcare costs associated with occupational and environmental diseases are burdening the U.S. economy with billions of dollars. In fact, it is becoming a common practice for U.S. companies to send their manufacturing operations offshore largely due in part to the staggering health care costs in the United States. Nanotechnology may potentially be used for the prevention, early detection, and treatment of occupational diseases (e.g., musculoskeletal disorders, pulmonary and cardiovascular diseases). A major theme of the research program is to provide a platform to exchange ideas on nano-health technologies for the prevention and treatment of occupational and environmental diseases.

The main goals of the proposed research program will be accomplished through the following three aims:

- Provide a forum for the exchange of ideas and research agenda on nanotechnology impact on health and environment including (1) occupational health in nanomanufacturing enterprises, immediate surroundings, and disposal activities, and (2) consumer public health.
- Provide a forum for the exchange of ideas and research agenda on the use of nanotechnology in prevention, early detection, and treatment of specific occupational and environmental diseases.
- Disseminate the latest research findings on nanotechnology related to occupational, environmental, and public health and safety.

These goals are translated into specific research program advances by developing a national research agenda for the impact of nanotechnology on (a) occupational health along the life cycle of nano-based products. Moreover, they can deal with the dissemination of the latest research advances on nanotechnology occupational, environmental, and public health and safety. Topic examples include but are not limited to, exposure assessment and control, public health, and nano-health technologies for prevention, detection, and treatment.

Note that, balancing theoretical versus experimental science, it is not unusual to find that it takes much longer to obtain a degree in a highly experimental field than in a more theoretical field (computer science or mathematics). Moreover, in addition to academic excellence, system safety students need to be able to conduct complicated laboratory procedures and work alongside other researchers in large and relatively structured research laboratories. Students in more theoretical fields tend to have more freedom when choosing the place, time and type of their work, and there is little or no focus on manual techniques. These differences make collaborative research and educational efforts between engineers and biologists a challenging task for faculty, students and administrators. In addition to dealing with the academic demands, students interested in systems safety will need to be able to move smoothly between multiple worlds and cultures.

5. Conclusion

Academia and industry alike have started to respond to the challenges posed by nanotechnology. This perspective article has focused on the academic arena, where learning communities are forming to train a new breed of system safety researchers to work effectively on multidisciplinary teams at the interface of various disciplines (e.g., material science, biology, engineering and computer science). The characteristics of the emerging nanotechnology research communities might differ somewhat between academic and industrial settings, but we believe that the type of researcher who will succeed in an interdisciplinary environment and the mechanisms that hold these multidisciplinary communities together, on a fundamental level, will be alike. When educating future safety system engineers, the challenge goes far beyond introducing students to the foundations of and latest advances in each others' disciplines. The proposed program will have a broad impact on industry and the public. The integrated solutions for the protection and promotion of individual health and safety will touch upon the well-being of stakeholders exposed to nano-based products along its life cycle, that is, workers, public consumers, and military personnel.

References:

[1.] Anderson L., and Krathwohl D. A taxonomy for learning, teaching and assessing: A revision of Bloom's Taxonomy of educational objectives; New York: Longman, 2001

[2.] Bloom B.S., Engelhart M.D., et al., Taxonomy of educational objectives: The classification of educational goals; Handbook 1: Cognitive domain; New York: David McKay, 1956

[3.] Bloom B.S., Taxonomy of educational objectives; Boston, MA: Allyn and Bacon, 1984

[4.] Hattie J., Visible learning: A synthesis of over 800 meta-analyses relating to achievement, Oxford: Routledge, 2009

[5.] Henri, F., Computer conferencing and content analysis; A. R. Kaye (Ed.), Collaborative learning through computer conferencing: The Najaden papers (pp.115-136); New York: Springer-Verlag, 1992

[6.] Johnson D.W., and Johnson R.T., Cooperation and the use of technology. In D. H. Jonassen (Ed.), Handbook of research for educational communications and technology, London: Prentice Hall Int., pp.1017−1044, 1996

[7.] Krathwohl D.R. A revision of Bloom's taxonomy: An overview; Theory into Practice, vol.41, pp.212−218, 2002

[8.] Kunen S., Cohen R., and Solman R. A levels-of-processing analysis of Bloom's Taxonomy; Journal of Educational Psychology, vol.73, pp.202−211, 1981

[9.] Mroz R.M., Schins R.P., et al., Nanoparticle-driven DNA damage mimics irradiationrelated carcinogenesis pathways; Eur. Respir. Journal, vol.31, pp.241–251, 2008

[10.] Nanoscience and nanotechnologies: opportunities and uncertainties, The Royal Society and the Royal Academy of Engineering, July 2004

[11.] Pena-Shaff J. B., & Nicholls C., Analyzing student interactions and meaning construction in computer bulletin board discussions; Computers and Education, vol.42, pp.243−265, 2004

[12.] Seaton A., Soutar, A., et al. Particulate air pollution and the blood; Thorax vol.54, pp.1027–1032, 1999

[13.] Slavin R. E., Research on cooperative learning and achievement: What we know, what we need to know; Contemporary Educational Psychology, vol. 21, Issue 1, pp.43−69, 1996

INTEGRATING SUSTAINABILITY ANALYSIS WITH DESIGN: CASE STUDY OF BICYCLE FRAME

Emmanuel Ugo Enemuoh, Ph.D.
eenemuoh@d.umn.edu
Department of Mechanical and Industrial Engineering
University of Minnesota Duluth
Duluth, MN 55812

Samuel Kwofie, Ph.D.
drskwofie@yahoo.com
Department of Material Engineering
Kwame Nkrumah University of Science and Technology
Kumasi, Ghana

Abstract
Designing a product to meet specific needs is the routine role of an engineer. The impact of a design to the environment is often times either minimized or ignored during the design process. The environment has some capacity to cope with impact from all human activities so that a certain level of impact can be absorbed without lasting damage. However, studies show that current human activities exceed this threshold with increasing frequency, diminishing the quality of the world in which we now live and threatening the well-being of future generations. Part of this impact derives from the manufacture, use, and disposal of products which are made from materials.

In this paper, integration of computer engineering analysis and sustainability analysis are used to evaluate three alternative materials for bicycle frame as follows; bamboo, aluminum, and carbon fiber epoxy. The assumptions used in the analyses were 250 lb (114 Kg) load on the seat tube while fixing the head tube, chain stays, and seat stays. This resulted in all of the materials to be well below the yield strength being under 3 MN/m^2 for each alternative design. The bamboo frame experienced the most displacement of 0.06 mm, followed by aluminum with 0.016 mm, and lastly carbon fiber reinforced epoxy with 0.01 mm. All of the deformations are significantly small compared to the diameter of tubing used so no fracturing will occur during use. The eco-audit tool is used to evaluate environmental impact of the alternative product designs using simplified Life Cycle Assessment (LCA) approach. The tool identifies different phases of the product life: material, manufacturing, transportation, and disposal by analyzing the specified material that carries the highest process energy, disposal energy, and which creates the greatest burden of CO_2. The eco-audit tool resulted in bamboo using the least amount of embodied energy and CO_2 compared to aluminum and carbon fiber. The material stage and manufacturing stage made up a significant portion of the total amount of embodied energy and CO_2 for all material choices.

This approach of evaluating the sustainability of alternative designs can be integrated with traditional design process taught in mechanical engineering programs. It will facilitate design of products that have minimal environmental impact and minimum embodied energy requirement.

Keywords: Sustainability, Embodied Energy, Eco-audit, and Environmental Impact

I. Introduction

The development of sophisticated products and global technological advancements coupled with the ever increasing use of non-renewable resources have led to the need to consider sustainability as an integral part of present and future developments. Also, it is important that the excessive dependence on depleting non-renewable resources be reduced drastically. This can be achieved with sustainability in mind during product development. Sustainability refers to the development of products that meet the present needs without compromising the ability of future generations to meet their needs. It considers the environmental impact, economic viability of products, and the social responsibility (people) of the product.

Bicycles are widely used in almost every part of the world and therefore it is prudent that the environmental impact of this product be considered as one of the design criteria. Bicycle frames are commonly made from materials such as aluminum, carbon fiber, and steel. The recent development of the bamboo bicycle frame, which came second in the world bicycle race has opened up opportunities to address questions such as: what material and manufacturing processes used in the production of the bicycle frame produces a more eco-friendly product and at the same time meets the stress criteria; which product is more sustainable?; is it the Bamboo frame, Carbon Fiber frame, or the Aluminum (metal) frame? A bicycle frame is the main component of a bicycle, on to which wheels and other components are fitted. The modern and most common frame design for an upright bicycle is a diamond frame and consists of two triangles: a main triangle and a paired rear triangle.

This paper presents the use of both sustainability analysis and computer engineering analysis to compare three alternative materials and manufacturing processes for making bicycle frames (diamond frame). Eco audit will be conducted on the three alternative bicycle frames. The eco data will include embodied energy usage, CO_2 emission, and water usage for each alternative frame. Then, finite element analysis of the frames will be conducted using SolidWorks software to determine the stress and deformation conditions of the frames during service.

II. Background

To evaluate the sustainability of a bicycle frame, a simplified life cycle assessment (LCA) is conducted. LCA traces the progression of a products life from raw materials to manufacture, usage, and disposal; documenting all resources consumed and emissions released at each stage of the life cycle. The results of the LCA will help both the manufacturer and the consumer to determine sustainability of a product. This will be facilitated with an eco-audit toolbox[2]. Eco-Audit will identify the phase of the product's life that carries the highest demand for energy, and which phase generates the largest CO_2 output. Figure 1, modified from Ashby[1] shows a rough diagram of the Eco-audit method. After the user inputs several variables into the program, the eco-audit tool draws various data from its databases of embodied energy of materials, processing energies, transportation type, and energy conversion efficiencies, to generate the energy breakdown and CO_2 footprint.

There are several eco-properties that the software uses to evaluate sustainability: the embodied energy, the CO_2 footprint, and the water usage. The embodied energy (H_m) is defined as the energy that must be committed to create 1 kg of usable material[1]. H_m is measured in the units of MJ/kg. To determine the embodied energy, the sum of the energies entering the plant in an hour is divided by the mass of the material being produced in an hour.

$$H_m = \frac{\sum \text{Energies entering plant per hour}}{\text{Mass of material produced per hour}} \; \frac{MJ}{Kg} \qquad (1)$$

The CO_2 footprint of a material is also determined in a similar manner, however the carbon emissions that are released upon creation of the material also include those created during transport, the feed-stocks and hydrocarbon fuels, and the electric power used by the plant. Therefore the final equation for calculating the CO_2 foot print is:

$$CO_2 = \frac{\sum \text{All contributions of } CO_2 \text{ production}}{\text{Mass of usable material exiting the plant}} \; \frac{(CO_2)}{Kg} \qquad (2)$$

The water usage is very straight forward. It is simply the amount of water that is used in the production of the product in question.

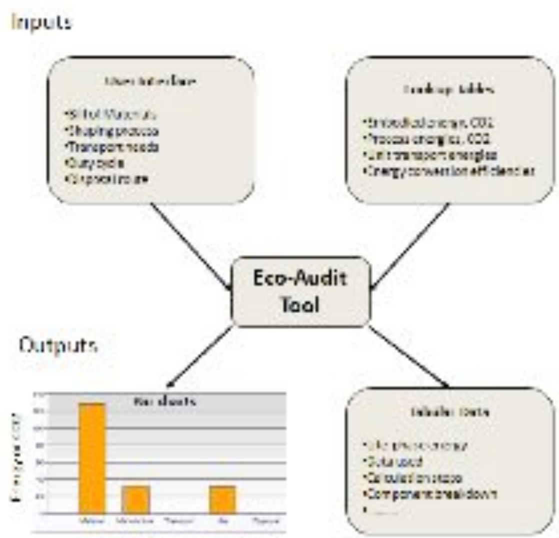


Figure 1: The Energy Audit Method

III. Procedure and Analysis

Bamboo Bicycle Frame. This frame is made from bamboo with the specifications in Table 1. The joints of the frame are formed by wrapping the joints with polytetrafluoroethylene (Teflon). Bamboo frames are made from that which has been smoked and heat treated to prevent splitting. For this product design, a propane torch is used for approximately 10 minutes to heat-treat the bamboo in order to seal the nodes and prepare it for baking. Baking is done at a temperature of about 350˚F for 1 or 2 hours. Figure 2 is an illustration of a bamboo bicycle frame.

Table 1. Bamboo bike frame specifications per component

Part	Outer Diameter (in.)	Inner Diameter (in.)
Head Tube	1.25	0.75
Down Tube	1.875	1.675
Top Tube	1.375	1.125
Seat Tube	1.375	1.00
Chain Stays	1.063	0.938
Seat Stays	1.00	.875
Pedal Tube	1.375	1.00

The bamboo bicycle frame consists of different size bamboo tubing and polytetrafluoroethylene (PTFE) is used to attach all the joints together. The bamboo is readily available in Ghana, Africa, hence does not require major transportation needs from overseas. The bamboo frame is shaped into the designed components with basic manufacturing tools: saw, drill, descent knife, rotary tool, and sandpaper. The PTFE that is used for the joints is formed through polymer molding. This does not require major transportation because a manufacturing plant can be found in Accra, Ghana. The bamboo bicycle frame is disposed by combustion at the end of its life, about 10 years expected duty cycle. The PTFE used to make the joints can be recycled.

Figure 2. A bamboo bicycle frame

Aluminum Bicycle Frame. The inside diameter of the aluminum bicycle frame is a little different from the bamboo frame with specifications illustrated in Table 2. Aluminum frames are generally recognized as having a lower weight than steel, although this is not always the case. The type of construction used for the aluminum alloy frame is tubes that are connected together by Tungsten Inert Gas (TIG) welding. They possess lower density and lower strength compared with steel alloys, however, possess a better strength-to-weight ratio, giving them notable weight advantages over steel.

Table 2: Aluminum bike frame specifications per component

Part	Outer Diameter (in.)	Inner Diameter (in.)
Head Tube	1.25	1.217
Down Tube	1.875	1.842
Top Tube	1.375	1.342
Seat Tube	1.375	1.342
Chain Stays	1.063	1.030
Seat Stays	1.00	.967
Pedal tube	1.375	1.342

Commonly made from 6061 Aluminum alloy tubing and aluminum filler rod, they are formed through the process of extrusion. Figure 3 is an illustration of aluminum bicycle frame. Hot liquid metal is poured into a die where it is then quenched to produce the desired hollow tubing dimensions. The tubes are joined together by TIG welding the same material aluminum, but in filler rod form, around the two faces to be held in place. The aluminum filler rod is made by pulling wire through a single drawing die. Transportation demands will be higher than bamboo, since they are either imported or transported from Accra, Ghana. At the end of the predicted 10 year life cycle, each component may be recycled.

Figure 3: An aluminum bicycle frame

Carbon Fiber Reinforced Epoxy (CFRE) Bicycle Frame. CFRE is among the latest materials commonly used for bicycle frames. Unlike bamboo and aluminum, CFRE is a composite consisting of carbon strands pressed together in layers within an epoxy. It can be shaped into interesting and aerodynamic forms; therefore, it is common to see carbon bike frames composed of teardrop, flat or wing shaped tubes rather than the perfect cylinders used in steel bike frames. CFRE bike frames are sometimes built as a single solid piece and they are sometimes built from individual tubes joined together with lugs much like a steel or aluminum frame. CFRE is very lightweight and can be made very stiff. Due to the alignment of the individual fibers, CFRE frames have a more distinctive grain structure. This allows it to have different amounts of stiffness in different directions and will stiffen non-linearly. Although CFRE is strong and stiff, a deep scratch or hard bump can compromise the structural integrity of its frame, making it prone to catastrophic failure.

CFRE Fiber bike frames needs a Polystyrene frame core for the carbon fiber to be wrapped. Along with the frame core and carbon fibers, an epoxy must be laminated in between the two components and around the joints to give the closely packed fibers the strength and rigidity it needs. Transportation needs for CFRE bicycle frames will be very high since the material is not readily available in the Ghana region; it must be air freighted from overseas. The product has a life span of 10 years where at the end of its life cycle the carbon fiber components will end up in a landfill and the polystyrene core will be recycled.

IV. Results and Discussion

Sustainability Results of the Three Alternative Designs. Analysis with eco-audit software shows that aluminum bicycle frame has highest embodied energy of 54000 kcal compared to CFRE bicycle frame with 44000 kcal. The bamboo bicycle frame has the lowest embodied energy of 34000 kcal as illustrated in Figure 4. The energy consumption at the material life stage of the three materials dominated the percentage of total energy consumption; about 86% and the other three life stages consumed only 14% of the total embodied energy. This information has a vital implication that a designer can focus on optimizing the material selection in order to design a sustainable product, since the other life cycle stages will contribute small percentage of energy consumed.

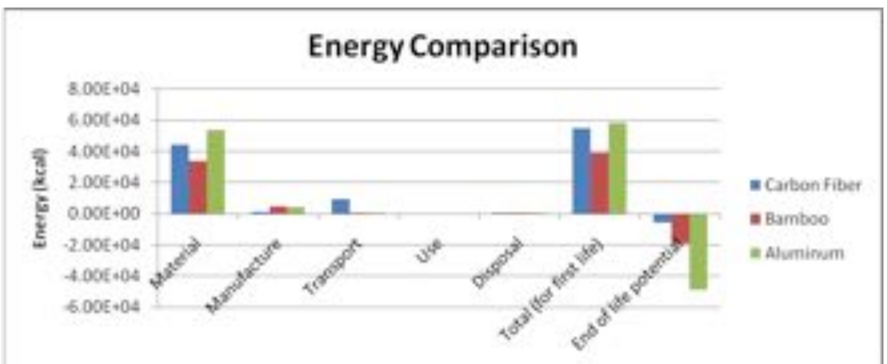


Figure 4: Embodied energy comparison of the three alternative designs

Similarly, the CO_2 emissions at the material processing life stage dominated the three materials' life cycle emission, comprising about 82% of the total estimated emissions. The processing of bamboo frame has the least CO_2 footprint of 16 lb, followed by CFRE with 23 lb CO_2. Aluminum bicycle frame has the highest amount of CO_2 emission of 28 lb (12.7 Kg) CO_2 as illustrated in Figure 5. Processing of the bamboo joints with Teflon tapes actually contributed 15 lb (6.8 Kg) out of the 16 lbs (7.3 Kg) CO_2 emission by bamboo bicycle frame. Bamboo has the least CO_2 footprint compared to the two other alternative designs because the Teflon emits 15 of the 16 total lbs of the CO_2 compared to the carbon fiber frame that lets off 20 (9 Kg) of the 23 (10.5 Kg) lbs and the aluminum frame releases 22 of the 28 lbs.

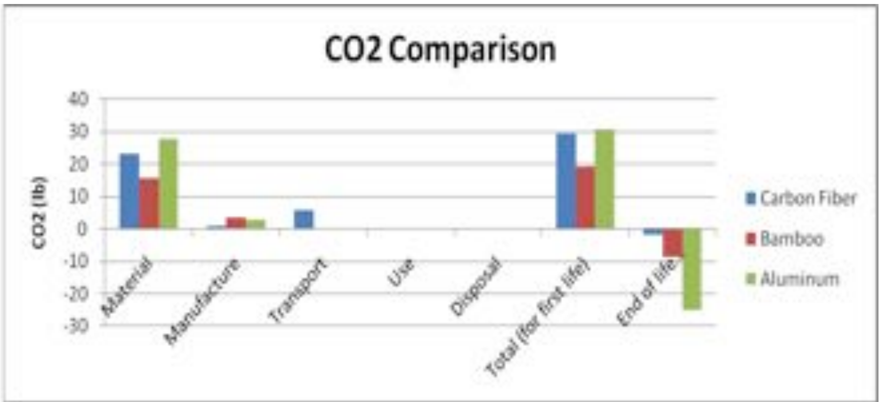


Figure 5: CO_2 comparison of the three alternative designs

The bamboo and the aluminum frame have a higher embodied energy for the manufacturing stage because of the energy used to make the joints (wrapping, extrusion and welding). Details of data from analysis of the three materials are shown in Tables 3, 4, and 5.

Table 3: Carbon fiber eco-audit results

Phase	Energy (kcal)	Energy (%)	CO_2 (lb)	CO_2 (%)
Material	4.45E+04	81.3	23	78.2
Manufacture	1.00E+03	1.8	0.71	2.4
Transport	9.15E+03	16.7	5.66	19.2
Use	0	0	0	0
Disposal	101	0.2	0.0654	0.2
Total (for first life)	5.47E+04	100	29.5	100
End of life potential	-5.80E+03		-1.65	

Table 5: Aluminum eco-audit results

Phase	Energy (kcal)	Energy (%)	CO_2 (lb)	CO_2 (%)
Material	5.39E+04	92.4	27.6	90
Manufacture	4.20E+03	7.2	2.91	9.5
Transport	54.1	0.1	0.0354	0.1
Use	0	0	0	0
Disposal	173	0.3	0.112	0.4
Total (for first life)	5.83E+04	100	30.7	100
End of life potential	-4.90E+04		-25.1	

Results of the Finite Element Analysis of the Frames.

The bamboo bike frame stress analysis shows a maximum stress of 2.8 MN/m^2, which is well below the yield strength of 39.6 MN/m^2 as shown in Figure 10. The maximum displacement of 0.06579 mm occurred at the seat stay and seat tube joints but is not a value that will result in fracturing of any of the tube or joints as shown in see Figure 11. The factor of safety for the bamboo bicycle is 14.3, which means that the frame can undergo 14.3 times the 250 lb (114 Kg) load set on the seat tube.

Figure 9: Bamboo design frame

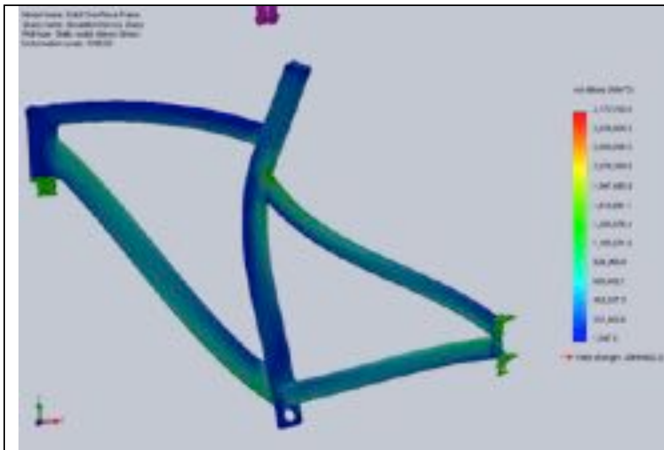
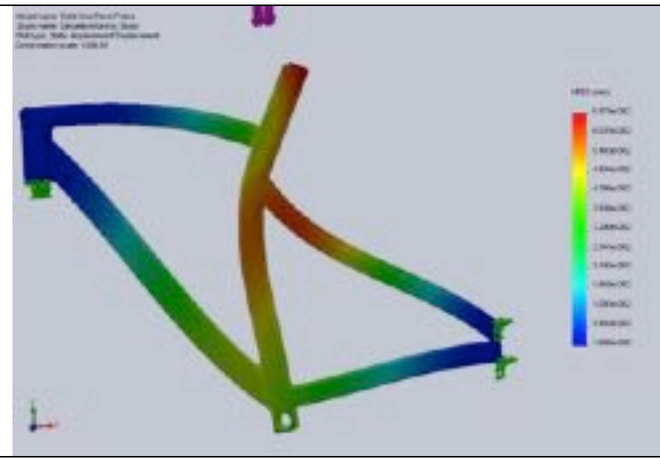
	

Figure 6.1 Bamboo maximum deformation	Figure 6.2 Bamboo maximum stress deformation

4.2.2 Aluminum Simulation Results with 250 lb (114 Kg) Load

The aluminum frames constructed out of 6061 aluminum alloy has a yield strength of 55.1 MN/m^2 and through the simulation express wizard on Solid Works produced a max stress at the same locations of the bamboo frame of 2.8 M N/m^2 as illustrated in Figure 13, and a max displacement of 0.016456 mm, which still is not a deformation that will cause any failure as shown in Figure 14. The factor of safety for the aluminum bicycle is 19.9 so the frame can withstand 19.9 times the 250 lb (114 Kg) load initially tested on the frame. The factor of safety is higher than that of bamboo frame.

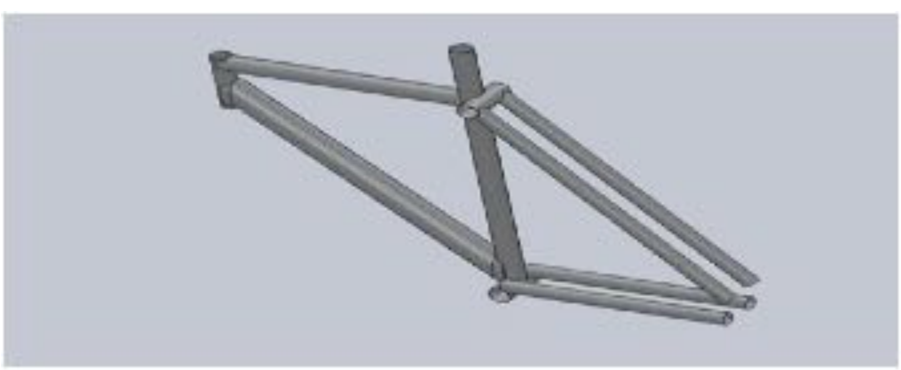


Figure 12: Aluminum frame design

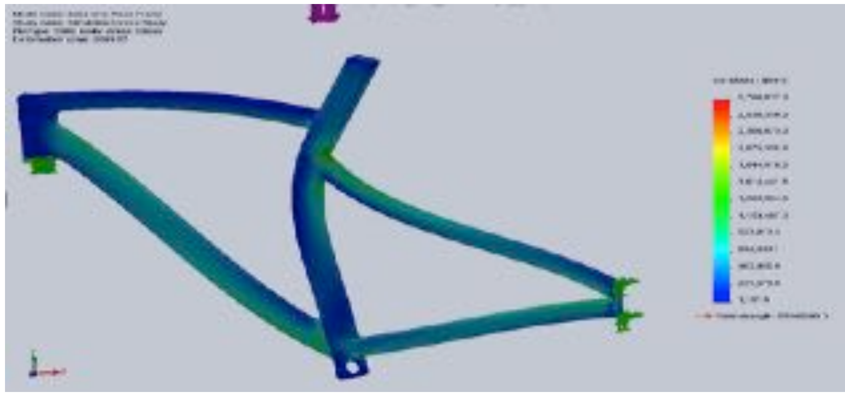


Figure 13: Aluminum maximum stress deformation

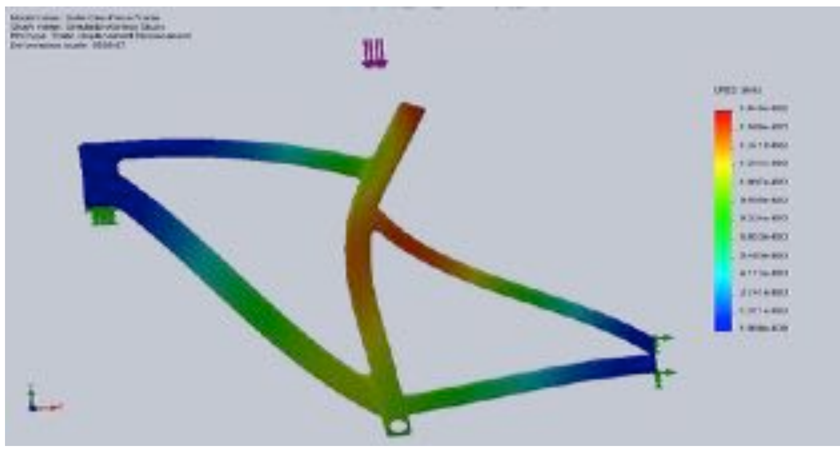


Figure 14: Aluminum maximum displacement

4.2.3 Carbon fiber Simulation Results with 250 lb (114 Kg)Load

The carbon fiber frame is similar to the bike frame constructed from aluminum alloy in that the max stress of 2.77 MN/m^2 is well below the yield strength of carbon fiber which is 800 MN/m^2 as shown in Figure 16. The maximum displacement is not a concern as well as it is only 0.01028 mm occurring at the same joints of the bamboo and aluminum frame, see Figure 17. The factor of safety for the carbon fiber bicycle is 248.9 so the frame can hold up 248.9 times the 250 (114 Kg) lb load placed on the seat tube.

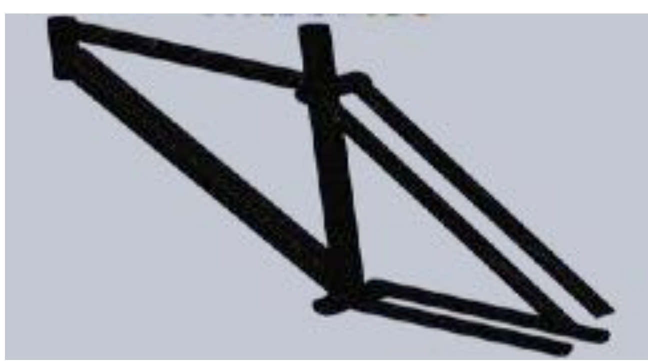


Figure 15: Carbon fiber design frame

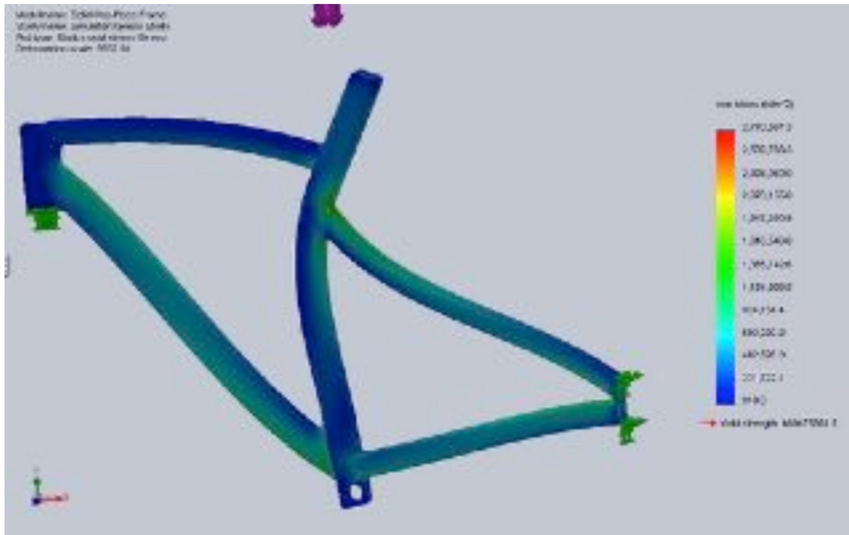


Figure 16: Carbon Fiber maximum stress deformation

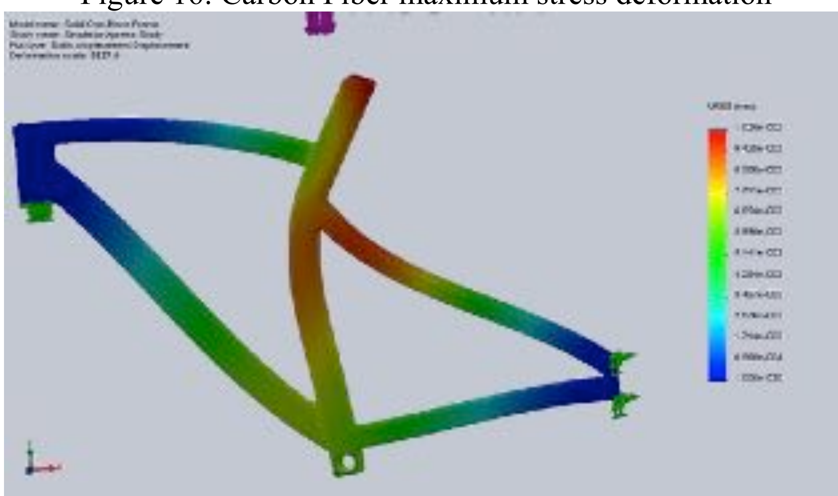


Figure 17: Carbon Fiber maximum displacement

V. RECOMMENDATION AND CONCLUSION

5.1 RECOMMENDATION

Since the assumption is that the production of the bicycle frame is in Kumasi, Ghana, the data indicates that it takes relatively lower embodied energy from cradle-to-death for the frame to be made from bamboo than aluminum and carbon fiber composite materials. The biggest portion of the embodied energy used to produce the three alternative designs is in the material phase. Aluminum requires the most amounts due to the extrusion and welding to produce the final product, followed by carbon fiber in second as it requires a lot of attention to successfully construct the frame. Bamboo material uses the least amount of energy emitted in the material phase because the adhesive is the only component affecting the final product. Also, the data indicates that the total CO_2 released into the atmosphere for the bamboo is almost half the amount compared to aluminum and carbon fiber. Therefore, the bamboo bicycle frame is the most sustainable and durable design to that of the aluminum and carbon fiber bicycle frames.

5.2 CONCLUSION

Designing and analyzing bamboo, aluminum, and carbon fiber bike frames using Solid Works and eco-audit tooling resulted in a thorough data stress analysis while also showing the carbon and energy footprint from raw materials, material production stage, product use, and disposal. Due to the difficulty of conducting engineering analysis of the different joints that the alternative bicycle frames using Solid Works, all the designs are assumed solid at the joints. Hence, the analysis is focused on materials.

It can be concluded from the FEA and Eco-Audit results and analysis that bamboo material being used as a bicycle frame will be more sustainable production than aluminum and carbon fiber composite in Kumasi, Ghana. All of the three alternative designs met the stress and displacement requirements so their sustainability comparison proves to be the next best criteria for deciding which materials and design to go with. The data presented in this document shows the facts on why bamboo is most sustainable as the total embodied energy and CO_2 emitted is significantly less than aluminum and carbon fiber bicycle frames. Combination of the CES EduPack software and the Solid Works software will be very valuable in designing both sustainable and robust engineering products. Designing and meeting the present needs to have a sustainable product while not compromising the future needs is a big issue and by considering sustainability at design stage, the planet, people, and profit can all progress to a better world.

References

[1] Ashby, M. F. (2009), Materials and the Environment: Eco-Informed Material Choice, Elsevier, Butterwork-Heinemann Publications.
[2] Granta Design Ltd (2011), EduPack Software, University of Cambridge.

Biography

EMMANUEL UGO ENEMUOH is currently an Associate Professor in the College of Science and Engineering at University of Minnesota Duluth (UMD). He has a Ph.D. in Mechanical Engineering. He has 10 years of college engineering teaching experience as well as one year Post Doctoral research experience. His teaching and research interests include engineering sustainability; engineering design; manufacturing processes; material science; and non-destructive evaluation methods.

SAMUEL KWOFIE is currently an Associate Professor in the College of Engineering at Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana. He has a Ph.D. in Applied Mechanics and has 12 years of college engineering teaching experience. His teaching and research interests include: physical metallurgy; fatigue and creep studies; material science; fracture mechanics; engineering sustainability; and manufacturing processes.

Keeping an Engineering Economy Course In-line With the Practice of Engineering

William R. Peterson, PhD, and Guanghsu Chang, PhD
Department of Automotive and Manufacturing Engineering Technology
Minnesota State University, Mankato

Abstract:
This paper addresses a perceived gap between the use of spreadsheets in the application of engineering economy concepts and tools in the classroom and in the workplace. Of particular concern is the use of tables in teaching the material and their absence from the workplace. The paper is based on the authors' experience in the workplace as practicing engineers/engineer managers and in the classroom teaching engineering economy at both the graduate and undergraduate levels. The authors also present the results of teaching the course using spreadsheets exclusively.

Background:
As suggested earlier, the use of spreadsheets for engineering economic type calculations is the norm in the workplace[1]. Even in 1980 practitioners were writing simple programs in Basic and other programing languages to calculate internal rates of return (IRR). In one instance which one of us was involved with, the calculations were done on a single board computer (an AIM 65). In this instance once the program had been written and saved, all that was required was the an input of the annual cash flows associated with a project and then a simple "do loop" was incremented until the net present worth was zero (assuming that the project started out at an interest rate of zero and gave a positive value. While seemingly crude, it allowed the cash flows to be irregular (which is extremely common in practice) and (assuming correct input of the cash flows) did not make math errors. While the program could have been made faster by a "better" search algorithm, it met the needs of the using organization.

At the same time, "MBA" (Masters of Business Administration) hand-held calculators were becoming available to do basic financial calculations such as find the payment on a loan (P) with interest (i) and period (n) based on the same underlying calculation in the tables is as a lookup value for "A/P, i, n".

By 1990 spreadsheets, such as Lotus 1, 2, 3 and Quattro, were readily available on personal computers (and larger computers) with built in financial sub-routines (which basically calculated the factor based on the i and n and then did the multiplication). There was even a subroutine to find IRR based on a cash flow (which basically did the same incremental search as in the AIM 65 example.

Engineering Economy continues to use the table approach with the texts being based on the tables with supplements and extensions in the chapters to address the use of spreadsheets (typically Excel). This has several reasons, but the most valid one in our opinion is that the Fundamentals of Engineering (FE) Exam is setup to use the tables for the engineering economy problems.

An Engineering Economics Course without Tables

Teaching and engineering economic course without the use of tables requires that certain issues be addressed in course preparation and design. These issues include:

1. If the students are to eventually take the FE exam, how will they be prepared to use tables to address the problems they will need to do on it?
2. How will the students access the spreadsheets in the classroom?
3. What text will be used since the texts use the tables?
4. What are the outcomes desired?

In the course we designed (and in an interim course in which project management and engineering economics were combined) we addressed these issues as follows.

The environment in which our course was offered was in an engineering technology program in a state where the engineering technology students are not automatically eligible to take the FE exam. Thus to a certain degree, Issue 1 above is not relevant. But to address this issue in a wider context, many programs do not include a course in engineering economics which covers 8% of the exam for industrial and mechanical engineers for example[3]. These programs typically rely on the material need to do the engineering economy problems on the FE being covered in one session (3 hours more or less) of a review/preparation course. This seems to work to the extent needed for the FE.

As to Issue 4 above, assuming the outcomes do not include Issue 1, the FE exam, then may vary. The ones for the course we were designing are as follow (the course was titled "Project Valuation"):

1. Explain the role of Engineering Value Analysis and it's connection to Project Management
2. Identify types of projects incorporating value analysis, such as make vs buy, new product design and development, product and process improvement, facility and infrastructure
3. Understand costing approaches and applications such as activity based costing versus traditional costing
4. Discuss and apply the concept of Overall Equipment Effectiveness (OEE)
5. Measure the project outcomes to organizational goals of cost, quality/performance and time.
6. Create and apply payback models and analysis
7. Develop Learning Curves and for their systematic cost influence
8. Gather key inputs for a capital project justification (CJP) proposal
9. Identify project evaluation techniques to include NPV and IRR
10. Assess, calculate, and apply the time value of money
11. Investigate, present, and discuss industry investment alternatives
12. Prepare and present a persuasive oral and written Capital Justification Proposal

While items 1, 4, and 5 above are course specific, item 10 is the cornerstone of engineering economy, and it is hard to imagine an engineering economy course without items 6 and 9. Items 3, 7, 8, and 11 are items which should be most engineering economy courses, and items 8 and 12 are why we offer the course. At the awarding of the degree this is where the graduate will use what he/she learned. This is also why we believe spreadsheets are a better approach since we can use real world problems which have irregular cash flows in lieu of the regular cash flows in standard text problems. We can use geometric gradients which seem to occur in practice in lieu of the contrived arithmetic gradients which we can handle with tables but do not see in practice. Additionally, in practice the major effort is represented by item 8 which in the typical text is given and is implied to be trivial.

Items 6, 9 and 10 are where spreadsheet calculations are done in lieu of tables and where this particular course approach differs from one using tables. While students need to understand the underpinning of what they are doing when they use a program (in order to ascertain of the “number” output makes sense) this can be as easily done with spreadsheets as with tables and maybe with more meaning since the basis is simpler – ever cash flow entry (CF_n) is worth, in terms of present value (PV_n), $CF_n/(1+MARR)^n$, where MARR (Minimum Attractive Rate of Return) is the interest rate which makes an investment valuable. This equation can be used to learn the concept prior to moving on to the functions (which do the non-value added programing/calculations – just like the tables).

This is where issue 3, which text book to use, becomes relevant. Since the text builds knowledge off of the use of the tables to solve problems, even if the lecture does not use tables, the supplied resource does and this is where the typical student goes to walk thru a homework problem. Having used a book as a supplement previously, we decided to not use a text book for this course. This is not a valid solution for all. In this instance the instructor had taught the course for over 15 years and writes in the area. Since engineering economy is typically as service course and assigned as such, for this approach to work universally, a text will need to be developed for many instructor to be comfortable with this approach.

Issue 2 probably requires either a computer classroom or access to a laptop by each student. In this instance the course was taught in a computer classroom with one computer per student. This should be less and less of a factor as we believe the laptop (or its equivalent) will soon replace the graphing calculator as the standard tool for an engineering student (just as the slide rule once was).

Teaching the Course

The course has been taught twice (Fall 2010 and Fall 2011) without a text and using spreadsheets as the tool for problem solving. Both semesters case problems[2] were used as a significant source of problems. The first offering had twelve students and the second had six – all in the program who were eligible. While these were small classes, in actuality the class of twelve was easier to teach than the class of six and 20 to 25 would be acceptable (we have taught other hands-on classes to include programing classes with these numbers).

The grade outcomes were normal (one D and one F in the first offering with both grades reflect not taking one of the three exams in the course – one student dropped the class in the second offering) with average grades of B+ and B. The learning/knowledge outcomes were judged to be good. The course evaluations by the students were 3.90 and 4.20 (out of 5).

Bibliography

1. Peterson, William R., Rafael E. Landaeta, and Bryan Magary, “Is It Time For A New Paradigm?”, *2005 ASEE Annual Conference and Exposition Proceedings* (June 12 – 15, 2005, Portland, Oregon), American Society for Engineering Education, Session 2639 (CD-ROM)
2. Peterson, William R., and Ted G. Eschenbach, Cases in Engineering Economy, Second Edition, Oxford University Press, New York, 2009
3. http://www.ncees.org/Exams/FE_exam.php (retrieved 10/7/2011)

GUANGHSU CHANG

Dr. Guanghsu A. Chang is a professor of the Automotive and Manufacturing Engineering Technology Department at Minnesota State University, Mankato. His research interests involve the study of robotic applications, manufacturing automation, Design for Assembly (DFA), and Case-Based Reasoning (CBR) applications. He holds both MSIE and Ph.D. degrees from the University of Texas at Arlington.

WILLIAM R. PETERSON

Dr. Bill Peterson is currently an associate professor at Minnesota State University, Mankato. He holds a BIE from Auburn University. He spent twenty years in industry during which time he earned an MBA. He has spent the last twenty teaching industrial and manufacturing engineering, engineering management, and the management of technology. He is a past president of SEMS and ASEM and the co-author of a book of case problems.

Engineering Targeted Project Design in Kinematics and Control Classes

Debao Zhou
Department of Mechanical and Industrial Engineering
University of Minnesota, Duluth, MN 55812, USA
Email: dzhou@d.umn.edu

Abstract

Labs and projects will be the important ways to solidify the knowledge learned from classes since hands-on work can help the students understand class materials better. A kinematics and control lab class has been offered in the Department of Mechanical and Industrial Engineering here at the University of Minnesota, Duluth. The projects in class have been designed to solve actual engineering problems. Through the projects, the students will not only use the learned knowledge to build creative products, but also the student can understand class materials better and accumulate more interest in class knowledge. By building up this positive feedback, the learning achievements can be maximized.

1. Introduction

Kinematics and control classes focus on the design and control of mechatronics systems with multiple degrees of freedom. In kinematics class, both the design and analysis of planar and spatial linkages have been emphasized. The class is mainly concentrated on the study of the posture, velocity and acceleration of complex linkages. The System Dynamics and Control class provides the method to describe the dynamics of a mechanical system and the method to control its behaviors. Being offered labs on kinematics and control, the students can have the actual opportunity to use the knowledge on an actual system. However, since all the labs are pre-designed and the students just followed the lab procedure, they still did not fully understand how to apply the knowledge to actual mechanical system. This is found out via the communication with the students. In order to make the students able to apply what they have learned from class, a project is designed during the kinematics and control labs. Through solving the problems they find in their everyday life, the students know exactly where the problems are and what they have to come out to solve them. After they have applied the knowledge and found how useful the knowledge is, they are excited about what they have done and build more interest on the class learning.

2. Project Design Requirements

For the project, the students are just asked to design, analyze and demonstrate a mechatronics system and provide evaluation to their final product, such as the analysis of the velocity, acceleration and position trajectory of a kinematic system and/or the analysis of the performance of their control system. The students are suggested to finish their design in three weeks by using totally 6 hours (two hours in each week). One group is formed by two students for discussion. In the first week, they are asked to do an extensive literature survey and find out what they want to build. In the second week, the students need to have a clear sketch about what they want to build and have the necessary components ordered. In the final week, the students are required to assemble their design and demonstrate how the design works. The students are also asked to prepare a comprehensive project report which includes introduction, literature survey, design description, results and discussion and conclusion. Finally, the students will be asked to give a 10 minutes presentation to introduce their design to the whole class.

Some equipment has been provided to the students. The first set of equipment is a kinematics kit [1] as shown in Figure 1. This kit includes a stepper motor, number of different links. The motor with control circuit is fixed on the white panel as shown in Figure 1. On the white panel distributed tapped holes with equal distance. The second set of equipment is a DC brush motor system with related data acquisition card, amplifier, power supply, function generator, oscilloscope and a computer with Matlab/Simulink as shown in Figure 2. The students are provided with the flexibility to disassemble the two sets of equipment to build their own design.

Figure 1, Kinematics kit (stepper motor is inside the box.

Figure 2, Motor and related equipment including hardware/software.

3. Typical Projects

In order to make the students finish the project in only 6 hours, the instructor suggested the students should consider one degree of freedom system in first priority such that the mechanism can be directly driven by the provided motors. Number of joints and links can be involved to achieve irregular or desired motion. The instructor also required them to make their design meaningful to fulfill certain engineering jobs. Due to this loss requirement and the connection with engineering, the instructor can feel that the students have great interest on the project design. They built a lot of interesting projects. Some of the projects are illustrated below.

3.1 Control Concepts: Projects Involving Direct Motor Control

Although you may think that a mechanism with one degree of freedom is simple, since it can be directly controlled by a motor, the students can verify the control theory in much easier way and they can concentrate on the understanding of the control theory. To realize the goal of real application, some students came out some wonderful ideas to apply the class materials, such as the ball balance project, light following for solar charger project, watering from a cup project, elevator simulator project, etc.

The design of the ball balance project is shown in Figure 3, where the orientation of a long beam is directly controlled by a motor and the motor is control by a PID controller. A Sharp GP2Y0A21YK wide distance sensing optoelectronic sensor is used to feedback the ping-pong ball position. The project used a Zeigler Nichol's PID tuning method to get the best ball balancing results. This is a wonderful example to apply class learned technology to solve engineering problems.

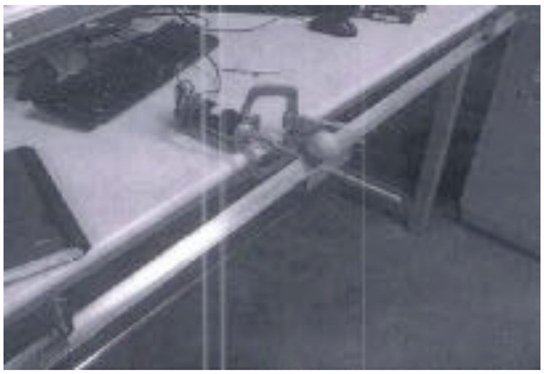


Figure 3, Ball balancing project.

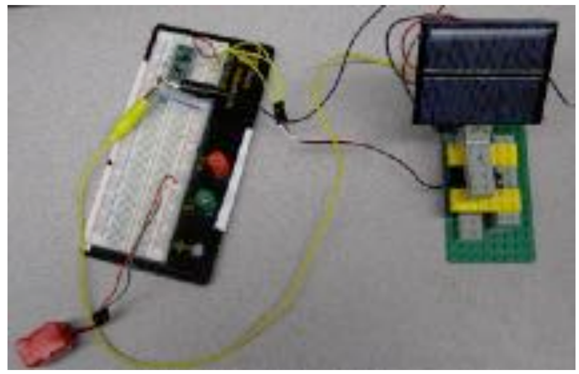


Figure 4, Light tracking for charging cell phone.

Another group of students used the direct control method to realize the tracking of sun light such that a cellular phone can be charged through a solar panel. The system is shown in Figure 4. A stepper motor was controlled by a microcontroller. PID controller is used in the microcontroller. The controller data are downloaded to the microcontroller from a personal computer after the tuning on computer. The feedback is from a light sensor which is just beneath the solar penal as shown in Figure 4.

After taking System Dynamics and Control class, the students have learned the basis of the classic control theories. However, they do not know how to apply them. By designing and controlling a mechanism themselves, the students have the strong feeling about where the controller is and how the controller works. This will build strong memory that they will never forget. Tuning in actual projects is the best way to gain and understand PID control theory.

3.2 Kinematics Concepts: Projects Involving Crank-Slider Mechanism

Complex planar linkages are involved in Kinematics class, where the analysis on position, velocity and acceleration may not very appealing to them. But when complex trajectory is involved, these planar linkages are very useful. Some of the students decided to realize some planar linkages and assign them actual applications. Two of the examples, the saw mechanism and the loco linkage, are shown below.

In the saw project, the students' though is to automate the wood sawing processing for labor saving. The slide crank mechanism learned from kinematics class will be an ideal candidate for this application. But the students did not stop after building this mechanism. They also did the kinematics analysis for the system. Through this experience, they know how to apply the learned knowledge to a real problem. Another group of students apply an accelerometer (ADXL321EB Dual-Axis Accelerometer from Analog Devices Inc. [3]) on the tip of the slider to measure the actual acceleration. Then the group compared the obtained acceleration with the calculated values using analytical method and the simulated acceleration from Solidworks Motion analysis software. After the comparison, what the students could say is “Amazing”. Through such a project, they have much better feeling about the theoretical linkage analysis.

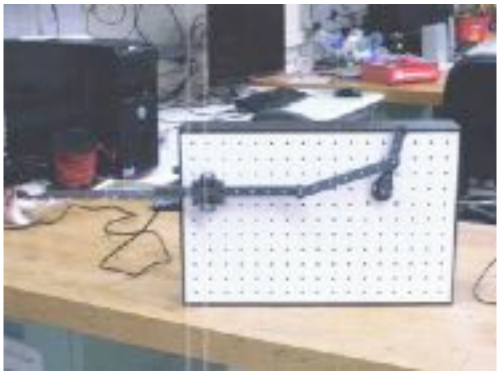


Figure 5, Saw project.

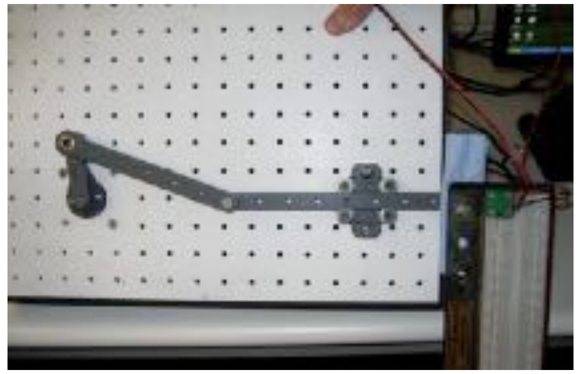


Figure 6, Loco motion with acceleration sensor.

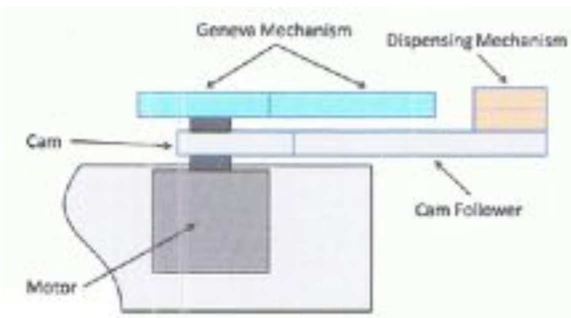


Figure 7(a), Mechanism illustration of the candy dispenser.

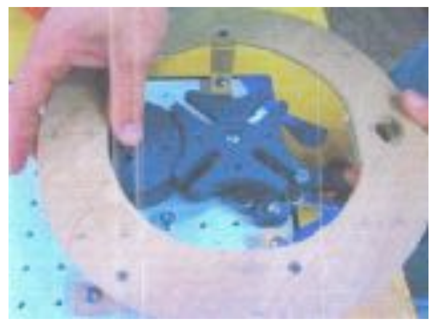


Figure 7(b), Geneva mechanism with wooden base.

Figure 7(c), Candy dispenser mechanism.

3.3 Projects Involving Complex Mechanism

Some students put their vision even further and they want to try more complex mechanisms. Candy dispenser is one of the examples that I want to show. The candy dispenser is capable of storing different kinds of candy. It can dispense the candy at variable speeds depending on what the control signal is set to. This is useful for a college student who likes a little variety in their junk food. This mechanism is a fairly complex machine that utilizes both Geneva mechanism and a cam with an offset follower [4]. There is only one degree of freedom in this mechanism. It was designed by first setting up the basic drive mechanism- the kinematics kit. Above the cam was the drive portion of the Geneva mechanism, which was fastened to the cam and hence driven by the motor as shown in Figure 7(a). The Geneva mechanism with the wooden base is then assembled as shown in Figure 7(b). Figure 7(b) also shows how the dispensing mechanism lines up with the hole in the base. This hole is where the candy containers line up with for the ¾ of the time that they are not in motion. As the cam turn, the dispensing mechanism moves back and forth with the follower. When the cam reaches its maximum displacement, a piece of candy is able to drop in the hole in the dispenser that begins to line up. Underneath the dispensing mechanism there is a stop that keeps the candy from falling all the way out of the machine while the cam is at its maximum displacement. Then as the cam returns to the position of no displacement, the candy is able to drop out of the dispenser and into the serving dish.

The conclusion from the group of students is "we found this to be a fun project to design that ties into the material we have covered in our kinematics class. It would be nice to see our machine implemented into a real life application." In my opinion, this project is really a creative design where a patent can be applied.

Beyond these projects, the walking spider project, obstacle avoiding robot project, nitinol powered walker project, and many others are very creative and interesting. Among them, the obstacle avoiding robot won the third place in the 2010 ASME Student and Mechanism & Robot Design Competition [5]. All these projects are inspired from engineering problems and in reverse, helped the students understand class materials better.

4. Conclusion

A project can help the students understand class materials better. An engineering targeted project can even build more interest for the students to understand the theoretical study in class. At the same time, engineering targeted project can generate creative ideas. Thus we should encourage such project activities for students to combine their class learning with actual engineering problems.

References

[1] Debao Zhou, http://www.d.umn.edu/~dzhou/ME-3222/Kinematics%20kits%20manual.pdf, accessed October 12, 2011.
[2] Sharp Inc. http://www.sharpsma.com/webfm_send/1208, accessed October 12, 2011.
[3] Analog Devices Inc. http://www.analog.com/static/imported-files/eval_boards/143456412ADXL321EB_0.pdf, accessed October 12, 2011.
[4] Kenneth Waldron and Gary Kinzel, Kinematics, Dynamics and Design of Machinery, 2nd edition, Wiley & Sons, 2003, ISBN-13: 978-0471244172.
[5] Jonas Swedberg, "Path Finding Track Vehicle", 2010 ASME Student Mechanism & Robot Design Competition, Montreal, Quebec, Canada, Aug. 15-18, 2010, http://www.stevens.edu/msrobotics/SMRDC2010/.

Academic Versus Industrial Senior Design Projects

Michael A. Rother
Department of Chemical Engineering
University of Minnesota-Duluth

For the past seven years, the Department of Chemical Engineering at the University of Minnesota-Duluth has used industrially supplied projects in its senior capstone design sequence. The change was implemented from academic to industrial projects as a result of an ABET recommendation to increase the multidisciplinary experiences of the students. By ABET definition, an industrially supplied project is considered multidisciplinary. The department does not charge companies for the student work. Instead, companies are solicited to provide projects voluntarily. Of the forty industrial projects completed, all have been obtained through departmental contacts, alumni or current students with coop or internship experience. Table 1 summarizes the raw data since the change to industrial projects.

Academic Year: 2004-5							
Group No.	1	2	3	4	5	6	7
Company	Windswept	WLSSD	MPCA	WLSSD	Sappi	Cargill	WLSSD
Topic	Al_2O_3	Bio H_2	Waste H_2O	Bio H_2	Black Liq.	Energy Int.	CH_4 prod.
Source	Student	Dept.	Alumnus	Dept.	Dept.	Student	Dept.
Implemented?	No	No	Yes	No	Yes	Yes	No

Academic Year: 2005-6						
Group No.	1	2	3	4	5	6
Company	Dul. Steam	Sappi	Faculty	Wasau Paper	CHS Oilsd.	Sappi
Topic	H_2O Pretreat.	Sludge Disp.	Orphan Drugs	Waste H_2O	Energy Int.	ClO_2 Prod.
Source	Alumnus	Dept.	Dept.	Student	Alumnus	Dept.
Implemented?	Yes	No	No	Yes	Yes	No

Academic Year: 2006-7						
Group No.	1	2	3	4	5	6
Company	MN Power	SSOE, Inc.	(Verso/NRRI)	Dul. Steam	Sappi	WLSSD
Topic	Hg Reduction	Biodiesel	Wood to EtOH	Hotel Heat	Anaerobic Dig.	CH_4 Fuel Cell
Source	Alumnus	Student	Dept./Alum.	Alumnus	Dept.	Dept.
Implemented?	Yes	No	No	Yes	No	No

Academic Year: 2007-8				
Group No.	1	2	3	4
Company	EcoLab	Dave Stark (Local Consultant)	CHS Oilseed	Sappi
Topic	Tank Design	House Design	Miscella Solvent Extraction	Hemicellulose to Ethanal
Source	Dept.	Dept.	Dept./Alum.	Dept.
Implemented?	No	No	No	No

Academic Year: 2008-9						
Group No.	1	2	3	4	5	6
Company	MN Power	CB&I	LSB Brewery	PolyMet	Arkema	Sappi
Topic	Fugitive Dust	Gas Plant	Carbonation/En. Integration	Acid Capture	Reactor Column	Digester Scrubber
Source	Alumnus	Student	Student	Dept./Alum.	Student	Student
Implemented?	Yes	No	No	Yes	Yes	No

Academic Year: 2009-10							
Group No.	1	2	3	4	5	6	7
Company	Fond du Lac	Verso	Cargill	N/A	Sappi	Barr	MPCA
Topic	Biomass Gasifier	Energy Integration	Optimization Corn Germ Dewater.	DME Production	Recovery Bolier	Zero Liq. Disch.	Phos. Removal
Source	Dept.	Student	Student	Student	Alumnus	Alumnus	Alumnus
Implemented?	Yes	No	Yes	N/A	No	Yes	No

Academic Year: 2010-11						
Group No.	1	2	3	4	5	6
Company	Fond du Lac	Fond du Lac	N/A	Sappi	Graymont	Barr
Topic	Biomass Gasifier	Wood Pellet Plant	Wood Torrefaction	Tall Oil Prod.	Energy Integration	Tank Design Permitting
Source	Dept.	Dept.	Student	Student	Student	Alumnus
Implemented?	No	Yes	N/A	No	No	No

Table 1: Summary of senior design projects over the last seven years.

1. Obtaining Projects

In mid-summer, as the instructor, I contact a variety of alumni and company representatives recommended to me by other faculty members about the possibility of sponsoring a design project in the coming year. The email contains a brief description of project requirements and the obligations of the industrial liaisons, as well as a disclaimer about student work being free of charge. In addition, the message informs potential sponsors that the demand on the contact person will be less than an hour a week, with the students asking most of their questions either at the beginning or toward the end of the spring semester. In general, the response to this first solicitation is weak - and understandably so, since engineers are busy and not looking for added responsibility with little obvious benefit. By the beginning of the fall semester, one or two projects may be lined up. Often, these are projects left over from the previous year.

Typically, once a company has supplied a project, it is willing to participate again. For example, I generally count on Sappi and Duluth Steam (see Fig. 1), which are both within driving distance of campus, to supply some work for the students, and both companies often have several project options. In October, the Industrial Advisory Committee (IAC) meeting takes place. Since the IAC consists predominantly of alumni, I make a public request for projects and then poll individual members as opportunity allows. By the end of November, when students are presented the available projects, the required number of alternatives has been obtained. However, it is not unusual for me to be working out details the week of Thanksgiving on one or more projects.

Figure 1: Sappi Fine Paper of Cloquet, MN (left) and Duluth Steam Cooperative (right) have provided 10 of 42 total projects in the last seven years.

One important source of projects is the students themselves. By their senior year, most of the students have completed an internship or coop and have good industrial contacts. At the beginning of fall semester and several times thereafter, I mention to the class the advantages of obtaining their own projects. As Table 1 shows, about 33% of the projects over the last seven years were arranged by the students. The CHS Oilseed project in 2005-6 (see Table 1) could perhaps be added to that number, since a student solicited an alumnus for the work. The student-obtained projects can work out very well, since at least one student is well versed in the topic. On the other hand, that one student often dominates the group.

As a point of information, it should be mentioned that students are not forced to take one of the projects on the list presented to them. They may try to obtain one on their own, if they are strongly opposed to their choices. However, I give them a limited amount of time to make their contacts after November, since they have already been given ample opportunity. Their other option is to do an academic project with at least one reactor and two separation steps. In the first five years, no group chose an academic project, although the Verso/NRRI project in 2006-7 (see Table 1) amounted to an academic project when the group and company made the mutual decision to stop the originally suggested work on bleach-water treatment. In the last two years, two groups did academic projects, both of which worked out very well.

The issue of why it is difficult to get new industrial sponsors remains – and whether a better solicitation method exists. As discussed above, the difficulty seems to reflect an attitude on the part of industry that the company liaisons will have to do a lot of work for little or no benefit. Another concern which potential sponsors often express is that much of the material in any project offered would be proprietary. Since the final design reports are in the public domain, many times companies decline to participate on this basis alone. To get around this obstacle, I generally point out that we can change specific numbers in the reports, so that there would be two versions, one for the company and one for the university. In several of the projects which have been completed in the last seven years, some process information has been omitted to satisfy industrial interests.

2. Characterizing Projects

Granted that the sample is relatively small, with seven years of experience it is now possible to make some observations about the switchover to industrial projects. First, as mentioned above, we note almost all projects come from departmental, alumni and/or student

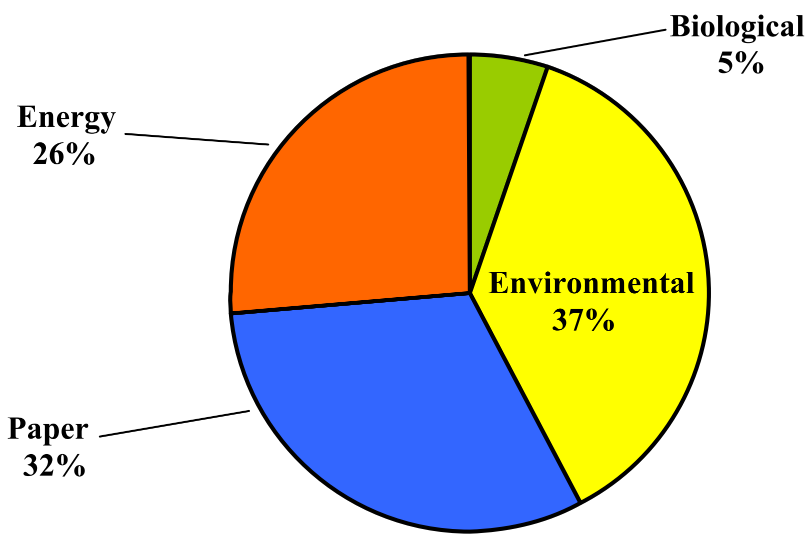


Figure 2: Breakdown of projects by area.

contacts. In other words, no projects have come from cold calling. Second, given the location of the university in northern Minnesota, most of the projects have been either environmental or paper-related. Figure 2 provides a rough breakdown of the projects. Some of the projects could be classified under more than one area, since the divisions are not mutually exclusive. For example, the Wasau Paper project from 2005-6 and several of the Sappi projects could be categorized as both paper-related and environmental or even biological in nature. Moreover, some of the Western Lake Superior Sanitary District (WLSSD) projects are both environmental and energy-related.

The relevant point, however, is that the vast majority of the projects do not involve making a final chemical product. The Orphan Drug project involved pharmaceuticals on a batch scale, so it was essentially specialty chemicals. The Windswept Energy project concerned production of alumina from anorthosite but developed into a study of the feasibility of wind energy. One of the Sappi projects investigated alternatives for production of chlorine dioxide (ClO_2). However, the chlorine dioxide is an intermediate used in the bleaching process and is not sold. Several of the WLSSD projects dealt with hydrogen or methane production, but the goal was to feed the gas into a fuel cell to produce energy for use on site or sale to the grid. The Verso/NRRI project involved batch-scale production of ethanol from wood for use in fuel. The ethanol production was driven by concern for renewable resources in energy and had mixed economic results. Only the SSOE, Inc. project to make biodiesel (and possibly the wood-to-ethanol project) was a true continuous process to make large quantities of a chemical product. Although biodiesel may turn out to be an important gasoline alternative, the project was clearly driven by Minnesota law and subsidy. In other words, biodiesel is not yet a commodity product in the traditional chemical engineering sense, such as petroleum products or polymers.

The types of projects which have been completed to date may reflect the changing nature of chemical engineering itself or the location of UMD, as mentioned above. However, an attempt to obtain a wider variety of projects may be in order.

3. Evaluating Projects

Experience with the industrial projects has been mixed. The previous academic projects were rigorous and provided a true capstone experience incorporating knowledge gained in many of the undergraduate courses. Design of a novel process involving one reaction and two separation steps was required. The industrial projects are typically not as demanding or as broad in scope. In fact, less than of the forty industrial projects could be considered to satisfy the previous academic requirements. Moreover, two of those projects, the Orphan Drug and Verso/NRRI projects, were quasi-academic anyway. That is, the Orphan Drug project was sponsored by a faculty member and the Verso/NRRI project turned into a student-driven study on production of ethanol from wood on a batch scale.

A Block Flow Diagram from one of the industrial projects is provided in Figure 3. Although the example is an extreme one, it does illustrate some of the problems that can be encountered. The scope of the project involved switching over from a solid nutrient feed system to a liquid one for a rotating biological contactor wastewater treatment system at Wasau Paper. Essentially, the students needed to get some vendor quotes for the appropriate liquid nutrients design some tanks with piping, and do the economics. I asked the group to do some work on the necessary control system, which was an interesting problem. However, Wasau Paper was satisfied with their existing controls, so it was difficult to motivate the students. The project was not a capstone experience.

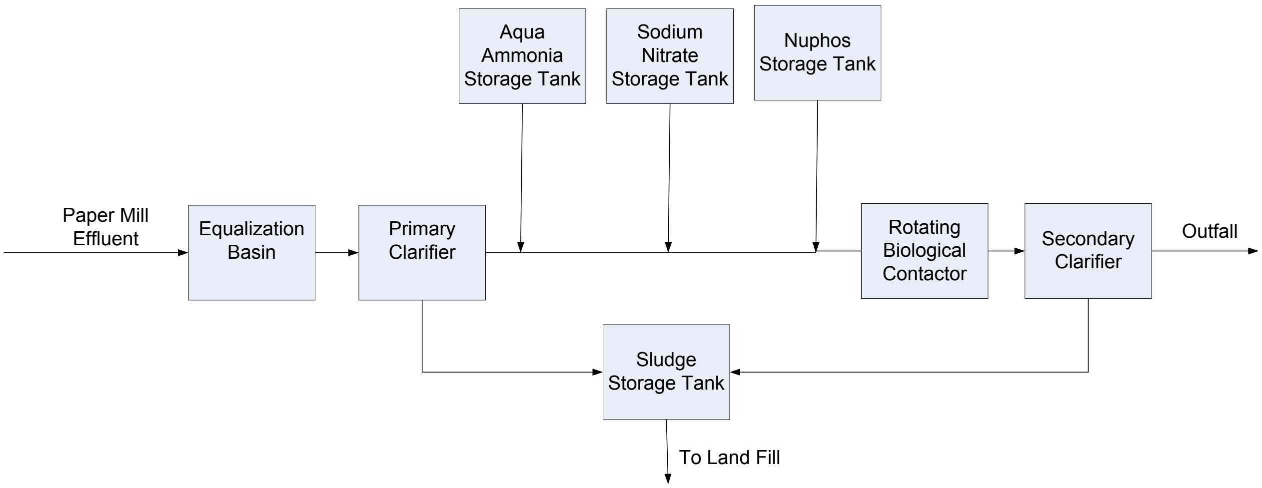


Figure 3: Block Flow Diagram from Wasau Paper project (See Table 1, 2005-6).

With the industrial projects, the students do gain practical experience dealing with vendors and contacts from the sponsoring company. Because the students do not actually work for the sponsors, vendors are sometimes unwilling to provide quotes, since they expect no purchase to occur. I tell the students to obtain permission from their industrial liaisons to say they represent the company or ask the liaison to obtain the quote him/herself. One problem that sometimes occurs is that students rely too heavily on vendor quotes. They are told to size and cost equipment themselves, as well, to check the vendor numbers.

The difficulties students encounter are often similar to ones they will meet as they enter the workplace. Moreover, over one third of the projects end up being implemented in some form, so that the students get the satisfaction of seeing their work in action. (Depending on how 'implementation' is defined, in 15 of the 40 projects, changes were made in existing processes along the lines of student recommendations.) In the case of the MN Power project, the students researched a technology (SAMMS) the sponsor had not considered. After testing, it was found that mercury levels were successfully lowered below 1.3 parts per trillion.

4. Improving Projects

To counter the academic shortcoming, the department sometimes supplements a project with an academic component. For example, the Duluth Steam project from 2006-7 was a feasibility study of adding some downtown hotels to the heating loop. Some heat exchangers needed to be designed, an energy balance performed and economics evaluated. However, the scope of the project was far from the traditional academic projects. After some discussion, several of the faculty decided to add a problem on optimum insulation thickness for piping to the project. Although the project was still not as rigorous as some former capstone experiences, it was improved. At our last ABET meeting in May, we agreed as a faculty to meet in October or November, when the projects are lined up, to discuss which topics need strengthening and how to make them more academically rigorous. An alternative which has been discussed but left on the table is to have the students do the AIChE Design Competition project in the fall as an additional individual project. One difficulty with this idea is that there really is not enough time in the semester for more work.

5. Conclusions

In moving from academic to industrial projects, we have found that departmental contacts are most helpful initially. Local industry provides the vast majority of the projects through alumni and current students, and companies are often willing to offer projects again after they have gone through the experience once. Patience is required since many new contacts may result in only one or two projects. For a relatively small department, such as chemical engineering at UMD, the types of projects obtained are generally dictated by the nature of local industry.

The change to industrially supplied senior design projects has been beneficial for the department. It has helped satisfy ABET requirements for multidisciplinary activities and gives the graduating seniors a practical experience as they prepare to enter the job market. It is true that academic rigor can sometimes suffer, but with careful monitoring it is hoped that a true capstone experience can be achieved together with real-life problem-solving.

Biographical Information

MIKE ROTHER is Associate Professor of Chemical Engineering at the University of Minnesota-Duluth. He received his Ph.D. from the University of Colorado at Boulder in 1999, and his research area is transport phenomena in the study of drops and bubbles. He teaches fluid mechanics, transport phenomena and senior design.